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VOLUME 1

PROCUREMENT

AN AMC QUALITY ASSURANCE REGULATION

AMC NONDESTRUCTIVE TESTING INSPECTION REGULATION

VOLUME 1

RADIOGRAPHY

HEADQUARTERS, U. S. ARMY MATERIEL COMMAND NOVEMBER

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PREFACE

This is one of a series of volumes covering the field of nondestructive testing inspection used to accomplish quality assurance operations in the inspection and acceptance of Army material. As a series, these volumes constitute the Army Materiel Command's Regulation 715-501 on Nondestructive Testing Inspection.

The purpose of this volume on Radiography is to provide Army Materiel Command quality assurance personnel with the basic principles underlying the radiographic inspection technique. The subject matter covered includes a history of the development of industrial radiography, the theoretical basis for radiographic inspection, sources of X- and gamma radiation, various types of equipment and applicable techniques, specifications and standards, and safety. A glossary of radiographic terms is given to aid the reader, and an appendix presents an analysis of radiographic qualification procedures. It is intended that this volume serve as a reference in which answers may be found to the more general questions concerning the technical aspects and applications of radiographic inspection.

The information contained herein is presented in recognition of the need for increasing and enhancing the information available to engineering and inspection personnel so they may better perform their assigned duties. It is hoped that such personnel will be stimulated by this publication to seek further information in more extensive works on the subject.

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CHAPTER 1

INTRODUCTION

Section I. PURPOSE AND SCOPE

1. PURPOSE

The purpose of this pamphlet is to provide technical guidance to U. S. Army Materiel Command (AMC) engineering and inspection personnel in the general field of radiographic inspection.

2. SCOPE

a. This is one of a series of publications in the field of nondestructive testing which, as a group, constitute the AMC Nondestructive Testing Inspection Regulation, AMCR 715-501.

b. This pamphlet contains technical and instructional data sufficient in overall scope and detail to provide engineering and inspection personnel with the availability and applicability of techniques using radiographic principles for the determination of materials properties.

Section II. HISTORY

3. GENERAL

a. X-rays were accidentally discovered in 1895 by Wilhelm K. Roentgen, a professor of physics at the University of Wurtzburg, Germany. While studying the phenomena of electrical discharges through rarified gases, he observed a new type of radiation. He called it X-radiation because of its peculiar and unknown nature.

b. When Roentgen announced his discovery, nearly everyone having a high-voltage gaseous discharge tube tried taking X-ray pictures of such things as human limbs and metal objects. These efforts were not very successful, however, since the tubes of that time usually failed when the high voltages necessary to produce X-rays of suitable penetrating power were applied. Moreover, the electrical generating devices used then produced very little current. This meant that exceptionally long exposure times were required. Since today's industrial type X-ray films were unknown at that time, the early radiographer was forced to use ordinary glass photographic plates which did not lend themselves favorably to radiography. All these factors, together with others, retarded the development of X-radiation for industrial use until about 1912.

4. DEVELOPMENT OF RADIOGRAPHIC INSPECTION

a. The development of radiographic inspection was accelerated when, in 1912, Dr. William D. Coolidge, an American physicist, perfected a new type of X-ray tube which could operate at higher voltages and carry more current than previous tubes. This resulted in X-radiation of greater intensity and penetrating power. Although radiography was used to some extent during World War I for various inspection purposes, it was not until the 1920's that its potential as a practical nondestructive testing method for industrial applications was proven.

b. In 1922, radiographic equipment using a Coolidge tube capable of operating at 20,000 volts (20 kv) with a current of 5 milliamperes (5 ma) was installed at the Army Ordnance Arsenal at Watertown, Mass. (fig. 1). With the installation of this equipment, pioneer efforts were made which led to the first real accomplishments in industrial radiography. After carefully completing evaluation studies of this new 20 kv equipment, Watertown Arsenal engineers and physicists found that up to three inches of steel could be radiographed under manufacturing conditions. These tests showed that a closer check could be kept on the quality control of forgings and castings.

c. Today, many foundries rely heavily upon radiography to inspect castings. Prior to the use of radiography as an inspection tool, casting defects, if discovered at all, were not found until the machining phase of manufacturing; this resulted in a loss of time, material, and money. Today the foundryman and radiographer work hand-in-hand. When a part is to be cast, a pilot casting procedure is set up, and the part is cast and radiographed. If the radiograph shows the part to be defective, changes are made in the casting technique and the part is recast. This process is repeated until a satisfactory procedure, yielding sound castings, is developed. A continuing quality check is kept by inspecting a number of castings selected at random out of a given lot.

d. In the early 1930's, radiographic standards were established for boilers and other vessels subject to severe pressures. Eventually, X-raying of pressure vessel welds became a common practice. In 1932, a new Coolidge X-ray tube, that would perform continuously at 300 kv and 8 ma, became available. As technology advanced, X-ray equipment with 1,000 kv tube ratings became possible. Then, with the development of the Van de Graaff generator and betatron, multimillion volt units were designed. Today, X-ray units, called linear accelerators, have ratings up to 100 million volts.

e. In recent years, technological advancements in the photographic industry with respect to film emulsion and strip film, have made possible far greater industrial use of radiography. In addition both government and industry are emphasizing continued effort toward the improvement of filmless radiographic techniques (e.g., fluoroscopy, xeroradiography, television, etc.).

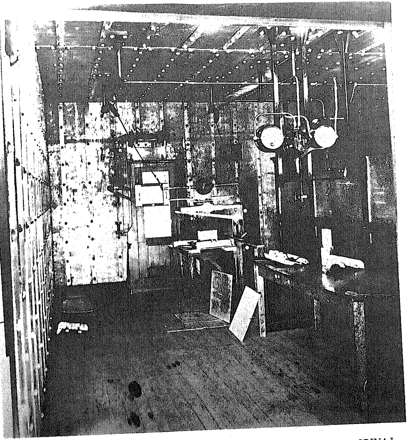


FIGURE 1. THE LEAD - LINED EXPOSURE ROOM OF THE ORIGINAL X - RAY LABORATORY AT WATERTOWN ARSENAL AS IT APPEARED IN 1922

f. A history of radiography would be incomplete without mentioning sources of radiant energy other than the X-ray tube. Radium is such a source. It occurs in nature and is used as a source for gamma radiography. Other sources are radioactive isotopes of certain elements. They were first produced in the late 1930's in a cyclotron, in small quantities and at great expense. With the advent of the atomic reactor, these isotopes could be produced in greater quantities and gave impetus to the field of gamma radiography by placing this inspection method within the reach of all industries.

CHAPTER 2

PRINCIPLES AND FUNDAMENTALS OF RADIOGRAPHY

Section I. PRINCIPLES OF RADIOGRAPHY

5. GENERAL

X- and gamma radiations have the ability to penetrate material that is opaque to visible light. During passage through material these radiation are absorbed to varying degrees, dependent upon the density and the atomic number of the material. This differential absorption phenomenon is used to render information which is recorded or imaged upon a film.

6. CONCEPTS

a. X- and gamma radiations, because of their unique ability to penetrate material and disclose discontinuities, have been applied to the radiographic inspection of castings, welds, metal fabrications, and non-metallic products. Radiography has proven a successful tool with which to implement quality control at all of its various stages. Process contr is one of the areas wherein radiography has been widely applied. The use of radiography to assist in the development of products and systems prior to production has resulted in considerable savings in time and cos

b. The three major steps concerned in this method of inspection are

(1) Exposure of the material to X- or gamma radiation, including preparation for exposure.

(2) Processing of the film.

(3) Interpretation of the radiograph.

c. Figure 2 is a diagram of a radiographic exposure showing the fundamental elements of the system. The penetrating radiation passes through the object and produces an invisible or latent image in the film. When processed, the film becomes a radiograph or shadow picture of th object. Since more radiation passes through the object where the sectic is thin, or where there is a space or void, the corresponding areas on the film are darker. The radiograph is read by comparing it with the known or intended design of the object and noting either the similarities or differences.

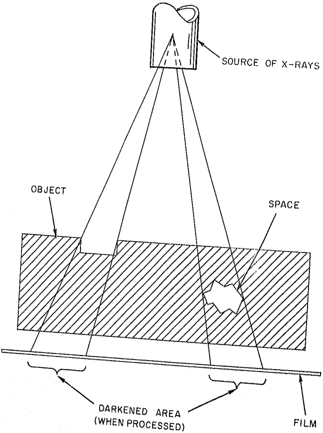


FIGURE 2. DIAGRAM OF RADIOGRAPHIC PROCESS

7. ECONOMICS

a. Radiographic inspection is superior to other methods in a number of applications. It is one of the nondestructive testing methods and provides a permanent visual representation of the interior of the test object. The application of radiographic inspection as a quality control procedure can conserve time and materials as follows:

(1) Reveals the nature of a material without alteration, damage, or destruction to the material, and can be used to separate acceptable from unacceptable units after standards for acceptance have been established.

(2) Discloses errors in the manufacturing procedure relative to process control in sufficient detail to indicate necessary corrective action.

(3) Discloses structural unsoundness, assembly errors, and mechanical malfunctions, thereby reducing the unknown or variable factors in a design during the development phase. It is useful in preventative maintenance and failure analysis.

b. Industrial X-ray film costs, plus the handling and processing expense, are relatively high in comparison to other inspection methods. Radiography of material which is small, easily handled, of simple geometry, and which otherwise lends itself to high rates of inspection, can be accomplished economically. Large items, complex geometries, material which is difficult to handle, or cases where the radiographic equipment need be brought to the material, are all factors which increase costs of inspection substantially. To illustrate: the cost of radiographic inspection of small metal components or assemblies such as small electron tubes, relays, etc., can be held to a low percentage of the value of the material; on the other hand, cost of complete inspection of critical metal parts or the preventative maintenance inspection of an assembly can sometimes exceed the cost of the material.

c. The successful application of radiography, from an economic viewpoint, lies in timely development studies and in-process control followed by the wise use of spot-check and statistical sampling measures. Of course, the cost of inspection is incidental to a cost in lives, money and time when failure of a material or component could cause the loss of a major item and result in a catastrophe.

8. LIMITATIONS

a. Radiographic inspection has several inherent limitations. The nature of the method wherein radiation traveling in straight lines from a source must intercept a film at nearly right angles, precludes the efficient examination of some items which have complex geometries. These conditions can occur under such circumstances that the film cannot be properly oriented or, if properly oriented, will be subject to the

adverse effects of scattered radiation or image distortion. It is often desired to determine a specific condition in a location which is surrounded by component material or items. Successful radiography, in these instances, could be impossible because of the confusion created by superimposed images.

b. The information depicted in a radiograph is obtained by virtue of density differences brought about by differential absorption of the radiation. These density differences, unless gross in nature, must be oriented almost parallel to the direction in which the radiation is traveling. Discontinuities of small volume, such as laminar type flaws, will often be undetected because they do not present a sufficient density differential to the radiation. Fortunately, this limitation is countered to some extent since the probable orientation of fractures can be approximately predicted and the radiographic set-up oriented accordingly.

c. The very nature of laminations precludes their ready detection, and radiographic inspection is seldom used to locate this type of flaw. Penetrating radiation is absorbed in direct proportion to the thickness of material. As material thickness is increased, the time required to obtain sufficient information on the film also increases. For a given energy (penetrating power) of X- or gamma radiation, there exists an economic maximum thickness beyond which radiography is not feasible. If the cost is warranted, radiographic equipment of higher energy potential could be obtained. Such costs increase markedly because of the barriers required to protect personnel from the harmful effects of the radiation as well as the basic cost of larger equipment.

Section II FUNDAMENTALS OF X- AND GAMMA RADIATION

9. CHARACTERISTICS OF X- AND GAMMA RAYS

a. X- and gamma rays are forms of electromagnetic radiation, as are visible light, ultraviolet light, infrared waves, radio waves, and cosmic rays. Altogether, they make up the electromagnetic energy spectrum. The wavelength, lambda(λ), of an electromagnetic radiation is expressed in units of length to suit the length of the waves, in meters (m), centimeters (cm), millimeters (mm), microns ($1\mu = 1/1000$ mm), in millimicrons ($1\,m\mu = 1/1000\mu$) or again for X rays in angstrom units ($1\,Å = 1/10\,m\mu = 10^{-8}$cm) and also for X- and gamma rays in X units ($1\,X = 1/1000\,Å$). Figure 3 shows the position of X- and gamma rays in the electromagnetic spectrum. The exact nature of this radiation is somewhat controversial. It was first considered that X-rays traveled in a continuous wave motion with a continuous rate of radiation. Later it was believed that this radiation was propagated in discontinuous bundles of energy or quanta. Valid arguments exist for both theories, and dual nature is considered to be present.

b. The distinguishing characterisitics of X- and gamma rays are their short wavelengths. The penetrating power, or energy, is dependent

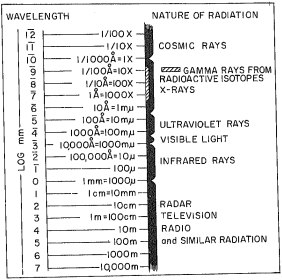


FIGURE 3. THE POSITION OF X - AND GAMMA RAYS IN THE ELECTROMAGNETIC SPECTRUM

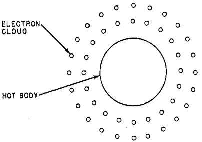


FIGURE 4. ELECTRON CLOUD AROUND HOT BODY

upon the wavelength in an inverse relationship; i.e., the shorter the wavelength the higher the energy, and the longer the wavelength the lower the energy. The wavelength of X- and gamma rays may be only 1/10,000th or less the wavelength of visible light. It is these short wavelengths that are responsible for many of the unusual properties of X- and gamma rays.

10. PRODUCTION OF X-RADIATION

a. General. X-radiation is produced when some form of matter is struck by a rapidly moving, negatively charged particle called an electron. Three basic requirements must be met to produce this condition:

(1) A source of electrons.

(2) A means of directing and accelerating the electrons.

(3) A target for the electrons to bombard.

b. Source of Electrons. If a suitable material is heated sufficiently, some of the electrons in the material will become so agitated as the temperature rises that they will literally boil off or escape from the material and surround it in the form of a cloud (fig. 4).

c. Directing and Accelerating Electrons. This cloud of electrons will hover about and return to the emitting material unless some external action or force pulls it away. Thus, movement of these electrons is the second step in producing X-rays. This movement is brought about by the repelling and attracting forces inherent in electrical charges. The fundamental law of electrostatics states that like charges repel each other and unlike charges attract each other. However, we are concerned with the attracting force. Therefore, a strong unlike or positive charge is used as an attracting force to move the electrons from one point to another. It is important that this movement be conducted in a good vacuum, otherwise the electrons will collide with air molecules causing ionization and loss of energy.

d. Bombardment. Merely generating electrons in a vacuum and setting them in motion is not sufficient to create X-rays. It is necessary also, that the electrons strike some substance. When the electrons bombard the target, certain atomic disturbances occur within the target material, releasing the radiations known as X-rays. X-rays are produced regardless of the state of material bombarded, whether it be a solid, liquid, or gas. In the X-ray tube, a solid material is used for the target. The higher the atomic number of the target material, the higher the efficiency of X-ray production. Unfortunately, only a small percentage of the energy available in the electron beam is converted into X-radiation; the remaining energy is converted into heat which must be dissipated by the target material.

11. PRODUCTION OF GAMMA RADIATION

a. Natural Sources of Gamma Rays. Many atoms exhibit a property called radioactivity which is a phenomenon of spontaneous atomic disintegration. This disintegration is believed to be caused by the instability of the structure of the atom under the action of the complex internal electric, magnetic, and gravitational forces. Radium is one of the elements with a natural unbalance that releases energy in the form of gamma rays to satisfy this unbalanced condition. In addition to the gamma rays, some alpha particles (helium atoms) and beta particles are emitted, but the gamma particles are more penetrating. The energy released is spontaneous and is a result of forces within the atom.

b. Artificially Induced Radioisotopes. Certain chemical elements can be rendered radioactive by subjecting them to neutron bombardment in an atomic pile. These elements are thus changed structurally and become known as isotopes of their original elements. These isotopes are unstable and therefore radioactive, and are termed radioisotopes. Their instability is characterized by their disintegration and the resultant emission of particles of matter and gamma rays. Hence, the radioisotope used in industrial radiography are basically elements which, through a change brought about by neutron bombardment, have become sources of gamma radiation. The most common radioisotopes currently in use in industry are derived from the elements cobalt, cesium, iridium and thulium, and are referred to as Cobalt 60, Cesium 137, Iridium 192 and Thulium 170. The numerical designation is indicative of the weight of one atom of the particular radioisotope and is useful in differentiating it from other isotopes of the same element or the parent element itself. For example, the cobalt atom in the normal stable state has an atomic weight of 59; i.e., it is 59 times heavier than an atom of hydrogen. The same atom upon capture of a neutron during neutron bombardment increases in wight to 60. Therefore the radioactive form of cobalt is designated as Cobalt 60.

12. RADIATION INTENSITY

a. General. Once X-rays have been generated or a source of gamma rays obtained, the intensity (the quantity or number of rays available during a specific period of time) must be determined. This factor is important because the time required to make a radiographic exposure is relative directly to the radiation intensity.

b. Intensity of X-Ray Generation. The intensity of X-rays produced in an X-ray tube by the collision of the electrons with the target is directly proportional to the tube current and is, in general, a function of the voltage raised to a power greater than 2.5. The efficiency of X-ray production is quite low at low voltages as demonstrated by the following relationship:

$$E \text{ (approx)} = \frac{ZV}{10,000,000}$$

where: E = efficiency in percent

Z = atomic number of target material

V = tube voltage

Therefore, the higher the atomic number and the tube voltage, the greater the efficiency of X-ray output. It can be seen from this approximate formula that even at 300, 000 volts the efficiency of X-ray production is only about 3 percent. This means that 97 percent of the input energy to the tube is dissipated as heat. The measure of radiation emission from an X-ray tube is stated in roentgens at a fixed distance for an established period of time. For convenience, the current flowing through the tube is referred to as the output of the X-ray machine. Because this current flow is directly proportional to the radiation emission, it can be used as one of the exposure constants for a given machine, and the intensity is often stated in milli- or microamperes.

c. Intensity of Gamma Ray Emission. Gamma ray intensity is the radiation emission from a radioisotope as measured over a given period of time and at a fixed distance. Intensity is cited as roentgens per hour per meter (rhm). The intensity of radiation is a function of the activity of a gamma ray source. Activity is the amount of radioactive material in a source: the amount in radium for example, is fixed by nature; in the case of artificially induced radioisotopes, the amount is determined by the extent of neutron bombardment. Activity is measured in curies (one curie equals 3.7×10^{10} disintegrations per second) and the intensity of radiation is a direct function of the activity. For example: one curie of Cobalt 60 emits 1.35 rhm; one curie of Iridium 192 emits 0.55 rhm.

d. Specific Activity of a Gamma Ray Source. The foregoing paragraph dealt with intensity as a function of time, distance, and activity. Intensity of radiation emission as a function of size is another factor which is important with respect to industrial radiography. For a given activity there could be a relatively large size source which might have only part of the basic element converted to radioisotopes or there could be a small, concentrated source where nearly all of the basic element is converted. The smaller one having the greater specific activity would be best suited for radiographic purposes. The degree of concentration of a radioactive source is termed specific activity and measured in curies per gram or per cubic centimeter.

e. Half-Life of a Gamma Ray Source. An X-ray tube can be activated to the same value of emission (generally cited in terms of milli- or microamperes of electric current) day-after-day, over periods of years. This is possible because in each instance energy is supplied from the electric power source. Radioisotopes, however, are like storage tanks from which energy is drained but not replenished. For this reason the intensity of emission is constantly decreasing. To illustrate: a Cobalt 60 source is activated to a value of 10 curies. At this time, at a distance of one meter, the radiation equals 13.5 roentgens in one hour.

sixty-four months (5.3 years) later, this same source has an activity of only 5 curies and emits only 6.75 roentgens per hour at one meter. The source has thus reached the point where one half of its strength has been dissipated. The time required to reach this condition is termed half-life. All radioisotopes have characteristic half-lives which differ in length depending upon the element. The half-life of a gamma source is used to determine the intensity of emission of the source at any time based upon its age. Dated decay curves are usually supplied with each source.

f. Intensity Versus Distance (Inverse Square Law). All reference to radiation intensity should be cited in conjunction with a specific distance from the source. Such reference to distance is essential because the intensity diminishes as the square of the distance. Briefly stated, if the distance from a given source is doubled, the quantity of radiation is required to cover four times the original area, and the intensity is therefore reduced to one fourth the original value. Conversely, by reducing the original distance by one half, then the amount of radiation present will be increased by four times the original value. Because intensity changes with the square of the distance, the relationship is termed the "Inverse Square Law" and this law is used extensively in computing industrial radiographic exposures. Expression of the inverse square law in terms of mathematics is as follows: The difference between the radiation intensities (I_1 and I_2) located at two different distances (D_1 and D_2) from a given source is equal to the inverse difference between the squared values of these distances. That is:

$$\frac{I_1}{I_2} = \frac{(D_2)^2}{(D_1)^2}$$

Figure 5 is a diagrammatic representation of the inverse square law in operation.

13. RADIATION QUALITY

a. General. The quality of X- or gamma rays is often referred to as the energy, wavelength, or penetrating power. The quality of the initial radiant emission is established at the time it is generated.

b. Quality of an X-ray Beam. The radiation from an X-ray tube is a heterogeneous spectrum of wavelengths. The minimum wavelength in angstroms($1Å = 10^{-8}$ cms) generated in this spectrum is equal to 12,395 divided by the tube voltage:

$$\lambda \text{ min} = \frac{12,395}{V}$$

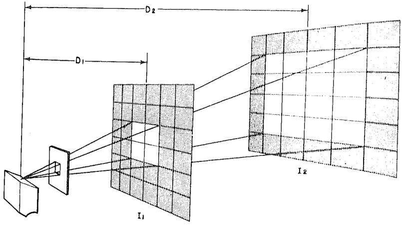


FIGURE 5. DIAGRAM OF THE INVERSE SQUARE LAW

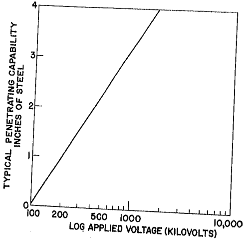


FIGURE 6. EFFECT OF INCREASING VOLTAGE ON THE PENETRATING CAPABILITIES OF AN X - RAY BEAM

where: λ = wavelength in angstroms ($\AA$)
V = volts

Changing the X-ray voltage changes the minimum wavelength produced in the spectrum. The wavelengths of maximum intensity are produced at the voltage which is approximately two-thirds of the highest voltage used. Figure 6 illustrates the relationship between the voltage applied to an X-ray tube to accelerate the electrons and the penetrating power of the X-rays. Figure 7 illustrates the distribution of the quantity (intensity) of X rays emitted in relation to the applied voltage. Note that increasing the intensity of X-rays (X-ray tube current) at a given maximum applied voltage raises the output curve but does not change its shape (distribution). Figure 8, on the other hand, illustrates the effect of increasing the maximum applied voltage. Note here that the penetrating ability increases (wavelengths become shorter) and the intensity of the radiation increases.

c. Quality of a Gamma Ray Beam. The quality of the radiation obtained from a radioisotope source is a characteristic of the element involved and is a constant. For example, Cobalt 60 emits only radiation of two specific wavelengths, 1.17 mev and 1.33 mev. Table I lists the isotopes commonly used in industrial radiography and the quality of their emission.

14. RADIATION ABSORPTION

a. General. The absorption by an interaction with matter is identical for both X- and gamma rays. The following paragraphs discuss absorption with regard to X-rays only.

b. Absorption. When X-rays strike matter, they are absorbed. The amount of radiation absorbed depends on wavelength of radiation, the kind and number of atoms in the absorbing medium, and its thickness. For monochromatic radiation, i.e., radiation of one wavelength, and for a homogeneous absorber, such as a sheet of pure copper, the fundamental law of absorption is expressed by this exponential formula:

$$I = I_o e^{-\mu d}$$

where: I = intensity of X-ray beam after emergence from absorber

I_o = intensity of X-ray beam falling on absorber

μ = linear absorption coefficient

d = absorber thickness in centimeters

e = 2.718, base of the natural system of logarithms

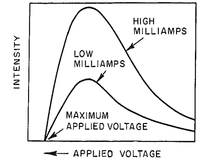
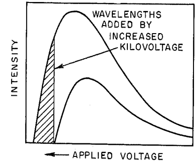


FIGURE 7. DISTRIBUTION OF RADIATION FROM AN X - RAY



IGURE 8. EFFECT OF INCREASING VOLTAGE ON THE QUA
AND INTENSITY OF AN X - RAY BEAM

Table I. QUALITY OF ISOTOPE EMISSION

Isotope	Gamma Emission Energy	
	Wavelengths	mev
Cobalt 60	2	1.17 - 1.33
Cesium 137	1	0.662
Iridium 192	3	0.296 - 0.316 - 0.468
Thulium 170	1	0.0842
Radium 226		0.7 - 0.8 (range)

c. Linear Absorption Coefficient. The linear absorption cofficient is the same for various thicknesses of absorbing materials as long as homogeneous radiation is used. However, X-ray beams used in radiography are composed of many wavelengths. It is possible to measure the radiation intensity falling on and emerging from an absorber for a heterogeneous beam, and to use the formula to calculate a coefficient of absorption "μ". The value thus obtained, however, will be an average coefficient of absorption dependent on all the factors of the absorption phenomena. This absorption coefficient value will naturally change with increased thickness of the absorber because the beam changes.

d. Factors That Determine the Mass Absorption Coefficient. The mass absorption coefficient "K" for any substance in a constant depends upon the state of matter, whether solid, liquid, or gaseous. Therefore, the mass absorption coefficient is equal to the linear absorption coefficient divided by the density or specific gravity.

$$K = \frac{\mu}{\rho}$$

where: K = mass absorption coefficient
μ = linear absorption coefficient
ρ = density in grams/centimeter

As a result, the intensity of an X-ray beam is not decreased as much by traversing one centimeter of steam as it is by passing through one centimeter of water. However, the linear absorption coefficient "μ" divided by the density of the substance is the same regardless of the physical or chemical state.

e. General Absorption Formula. The X-ray absorption of a substance in any state for a given X-ray wavelength is given by the ratio μ/ρ. This ratio, known as the mass absorption coefficient is the fraction of the intensity lost per unit mass thickness. Since $K = \mu/\rho$, then

$\mu = K\rho$. Substituting for μ in the exponential expression $I = I_o e^{-\mu d}$, the fundamental law of absorption then becomes

$$I = I_o e^{-K\rho d}$$

Mass absorption coefficient values (μ / ρ) for various wavelengths or radiation can be found in handbooks of chemistry and physics.

f. Interaction of X-Rays and Matter. Since X-radiation may be considered as particles (photons) traveling an electromagnetic path, there is an interaction between these particles and the atomic structure of the material through which it travels. The spaces between the nucleus and electrons of the atom are great in comparison to the space occupied by the particles themselves. Therefore, X-ray photons entering this matter will find paths of least opposition or interference as well as collision paths. Materials having low density have the greatest open spaces in the atom, while materials of higher density have less open spaces in the atom and offer a greater possible chance of collision between X-radiation photons traveling through the materials and the particles of the atom. This interaction between the atom and the X-radiation results in the absorption process which permits radiographic inspection of material by recording the radiation transmitted on a suitable film. In general, this absorption process follows the general absorption formula stated in the preceding paragraph.

g. Generation of Radiation. The energies involved in the collision and interaction of the X-radiation passing through the atomic structure results in a generation of radiation which is called scattered or secondary radiation since it does not come from the primary source or generator. This scattered radiation is classified by the three processes by which it is produced.

(1) Photoelectric absorption is due to the scattering and absorption of X-ray photons by the extra nuclear electrons of the specimen. This type of absorption is approximately proportional to the cube of the atomic number and falls off rapidly with increasing kilovoltage. Photoelectric absorption is accompanied by the emission of the characteristic soft X-ray spectrum of the absorbing material.

(2) Compton absorption occurs when an X-ray photon is deflected by an electron with an increase in wavelength.

(3) The third type of absorption, known as pair formation, occurs when the X-ray photon is transformed into a positron-electron pair. This phenomenon occurs only at kilovoltages above 1,000 kv (1 million volts) and increases with increasing kilovoltage, causing the rise in the total absorption coefficient at very high voltages. It is because of this rise in absorption

coefficient that 10 and 20-million volt betatrons are superior to 100-million-volt units for penetrating thick steel sections.

h. Scattered Radiation. Figure 9 indicates the complexity of the absorption and scattering of radiation. Because of these characteristics, any material submitted to the radiation field will, in turn, generate more radiation. This radiation is not image forming; instead, it reduces sensitivity of radiographic inspection and usually results in a foggy appearance in the radiograph since it tends to obscure the image. Filters, diaphragms, grids, masks and other radiation blocking devices are utilized to minimize this undesirable effect. Any material in the beam, whether specimen, cassette, table, walls, or floor receiving direct radiation is a source of scattered radiation. Unless suitable measures are used to reduce the effects of scatter, this secondary radiation will cause a haziness or fog over the whole image or part of it, thus reducing radiographic quality.

i. Variation of Absorption Coefficient with Wavelength. The variation of absorption coefficient with wavelength provides an easy means of reducing the proportion of soft rays in an X-ray beam. This is accomplished by passing the X-ray beam through a convenient thickness of a filtering material such as aluminum, copper, or lead. The softer components of the beam are almost eliminated, while the hard radiation is reduced only 50 percent or less depending on the thickness of the filter. The soft radiation is generally undesirable because it does not penetrate the specimen to help form the X-ray image, but it is very active in producing a type of scatter undercut. Figure 10 shows schematically the effect of a filter on the quality of an X-ray beam.

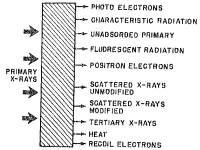


FIGURE 9. COMPLEX EFFECT OF PRIMARY X - RAYS

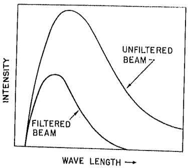


FIGURE 10. EFFECT OF A FILTER ON THE INTENSITY AND QUALITY OF AN X - RAY BEAM

CHAPTER 3

RADIOGRAPHIC EQUIPMENT

Section I. X-RAY EQUIPMENT DESIGN

15. GENERAL

It has already been shown that the three basic requirements for the generation of X-rays are: a source of electrons; an accelerating potential; and a material which will absorb the electrons and convert their energy to X-radiation. Modern X-ray equipment is the result of the development of these three basic elements of equipment design. The purpose of this section is to furnish the reader with general information on X-ray equipment design by examining this progressive development.

16. ELECTRON SOURCE AND ACCELERATING POTENTIAL

a. General. Prior to 1912, the intervening period between the discovery of the X-ray and the development of the incandescent cathode, X-rays were produced in gas-filled tubes. The process involved splitting gas molecules into ions and electrons with the application of high voltage. The resulting positive ions were drawn to the negative cathode and the electrons were set free by the ionic bombardment of the cathode. The electrons were then accelerated toward the anode (target), and X-radiation was produced by their absorption at the anode. The cathode usually consisted of an aluminum rod with a cup-shaped end which tended to focus the emitted electrons toward the anode. The electron supply, and thus the X-ray emission, was contingent upon the gas content of the tube. Provision was made to inject gas into the tube automatically. However, the intensity of the X-ray emission was highly erratic. Further, the presence of gas in the tube limited the voltages which could be applied because of the tendency of arc-over (breakdown) between cathode and anode. Thus, the wavelength of the X-rays was long and they had little penetrating power. From the standpoint of industrial radiography, the early gas-filled tube was inadequate. However, it should be pointed out that immense scientific strides were accomplished in the fields of material structure research by diffraction, fundamental studies of X-ray spectra, and the interaction of radiation with matter. Without this early effort, a foundation for the development of modern X-ray equipment would not have been available. The development by Coolidge of the incandescent cathode (heated metallic filament after Edison) was a major contribution to the improvement of X-ray equipment. The importance and basic nature of this development is substantiated by the fact that all modern X-ray equipment still uses this form of electron source. Figure 11 is a schematic illustration of the

early type Coolidge tube. Most modern tubes are refinements of this early type. Such refinements have been directed toward more consistent emission, longer life, and more efficient shaping and focusing of the electron beam. Also, the incandescent cathode required an evacuated (vacuum) tube to prevent oxidation or burning of the heated filament. This vacuum feature allowed the application of high accelerating potentials.

b. Accelerating Potential.

(1) Static induction machines and induction coils operating on direct current with interrupters were used to obtain the accelerating potential for early X-ray equipment. Storage battery systems capable of supplying 100 kv were developed and effectively used. These power sources had certain advantages such as consistency of the applied voltage; however, they were costly, bulky, and dangerous.

(2) Recognition of these drawbacks lead to a search for less expensive, more compact and safer equipment. The iron-core transformer fulfilled these needs. However, this device applied an alternating potential to the X-ray tube. During operation, the tube anode would become heated and emit electrons which would be accelerated to the cathode when the reverse potential cycle from the transformer was applied across the tube. The result was a second and undesirable source of X-rays, and the early destruction of the cathode. Several attempts were made to remedy this problem. Cooling of the anode to reduce electron emission was not entirely satisfactory. A mechanical rectifier (essentially a mechanical switch) was developed by Snook in 1908. This transformer pole changing device was used extensively for many years. However, the bulkiness of this device made it unsuitable for mobile equipment and the mechanical features were costly.

(3) Today's X-ray equipment uses a combination of tube rectifier and iron core transformer to develop accelerating potentials up to about 500 kv (fig. 12). Beyond 500 kv, the size and weight of the iron core transformer becomes prohibitive. Recognition of this limitation led to the development of the resonant type transformer as in figure 13. The resonant-type transformer does not have an iron core. Instead, the core of this transformer is practically all air. The design is similar to the "tank" coil used in radio transmitters. For X-rays, however, the high-voltage multicoil secondary is designed to resonate at a relatively low frequency, from 180 to 200 cycles per second. This principle of voltage generation is used in apparatus of 250 to 4,000 kvp range. The resonant transformer design permits a relatively compact light-weight generator because the associated multisection

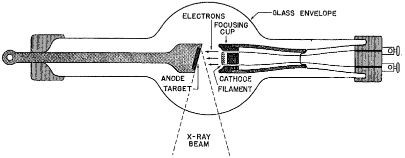


FIGURE 11. COOLIDGE TYPE X-RAY TUBE (SCHEMATIC)

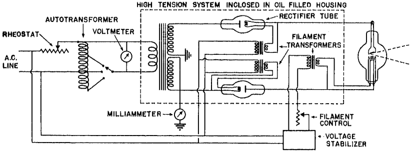


FIGURE 12. SIMPLE RECTIFIED CIRCUIT FOR X-RAY MACHINE

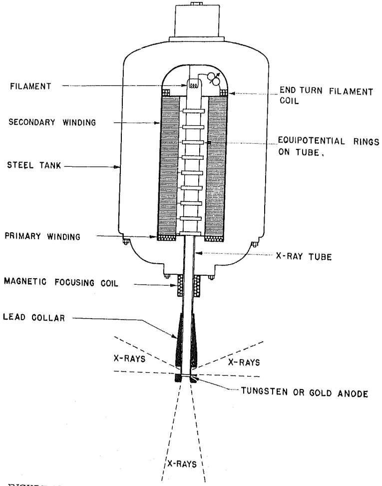


FIGURE 13. RESONANCE TRANSFORMER HIGH VOLTAGE X-RAY GENERATOR (SCHEMATIC)

X-ray tube is located in the central axis of the transformer where voltage gradients and fields are almost ideal. In addition, gas insulation is used.

(4) X-ray units which contain resonant type transformers are very useful but do have some drawbacks. Although the unit may be rated at 1,000 kvp, the actual radiation spectrum is broad and contains a large amount of radiation developed at energies much lower then this peak value. The fluctuation of exciting potential varies the velocity of the accelerated electrons and creates a focusing problem. This results in a focal spot larger than optimum. A smaller source size and a more coherent X-ray spectrum was achieved with the development of an effective electrostatic generator.

(5) The buildup of voltage by the electrostatic generator embodies two fundamental ideas: a conducting sphere will accept any available charge regardless of its own voltage, and the discharge of electricity will readily occur at pointed objects. As shown in figure 14, a non-conducting charging belt is driven by two motor-driven pulleys. As the belt passes the charging point, electrons pass from the point to the belt. This negative charge is carried upward where it is transferred to the corona cap at the corona point. The voltage which builds up is used to accelerate electrons supplied by a filament. A focusing coil controls the electron beam and focuses it on the anode. The equipotential plates are used to distribute the high voltage evenly on the X-ray tube. In actual practice, the generator is enclosed in a gastight chamber under pressure to minimize leakage of the high voltage. This type of design is used for voltages from 500 to 6,000 kvp.

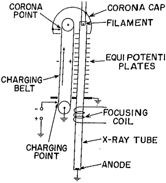


FIGURE 14. DIAGRAM OF ELECTROSTATIC GENERATOR

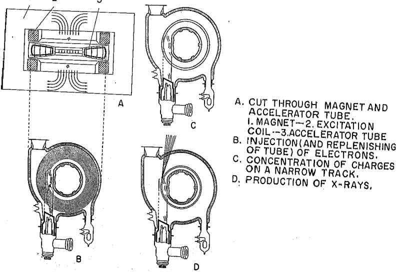


FIGURE 15. BETATRON RADIOGRAPHIC APPARATUS

to increase, and are accelerated by the voltage induced by the increase in the magnetic field (fig. 16). The electrons travel in a circular path inside the doughnut, increasing their energy on each lap. The electrons will circle through the "doughnut" many thousands of times in one cycle. When the field strength is no longer increasing and is about to decrease, the electrons are ejected by applying a pulse of current in an auxiliary coil to alter the magnetic field. The high-energy electrons are directed to the target and produce X-rays.

(7) Because the betatron utilizes a magnetic induction system, the physical size of the components is directly related to the electron velocities which can be obtained. To avoid this weight-size-velocity problem, a synchronized radiofrequency field system was developed to accelerate electrons. This device was named the synchrotron and is similar in operation to the betatron except for the nature of the induced field. The synchrotron permits the generation of higher energy X-rays than does a betatron of the same gross weight. This advantage is especially notable above the 50 mev range. Because these energy levels are higher than those normally considered of interest in industrial radiography, the synchrotron is used mainly for materials and physics research. Both the betatron and the synchrotron have one disadvantage which detracts from their wider application. The equipment and the instrumentation required to effect synchronized operation is extensive and complex. To overcome this deterrent, a simpler high velocity electron accelerating system was adapted for industrial radiography. This device, a linear accelerator, uses a straight length of wave guide tubing. Radiofrequency energy is coupled with this wave guide to accelerate the electrons which are injected into the system onto a target in a manner similar to that used for the betatron and synchrotron. The electron velocity attained in a linear accelerator is a related function of the length of the wave guide. Theoretically, infinitely high electron velocity might be obtained with very long tubes. Practically, the length of wave guide required to attain electron velocities equivalent to values used in industrial radiography is a matter of several meters.

17. X-RAY SOURCE (TARGET)

a. The third essential part of an X-ray tube is the target which absorbs the high velocity electrons and converts their kinetic energy to X-radiation. Three factors are involved in the design of the target: heat dissipation, the shape of the emitted X-ray beam, and the quantity of the X-radiation produced.

b. Early X-ray tubes used targets of molybdenum or tungsten positioned at a small angle to the cathode to project the X-ray beam as

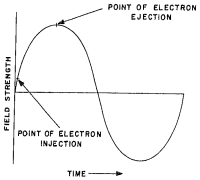


FIGURE 16. FIELD STRENGTH WAVEFORM FOR A BETATRON

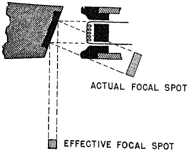


FIGURE 17. EFFECTIVE VERSUS ACTUAL FOCAL SPOT

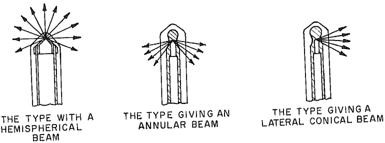


FIGURE 18. POSITIONING THE TARGET WITHIN THE ANODE TUBE TO OBTAIN VARIOUS BEAM CONFIGURATIONS

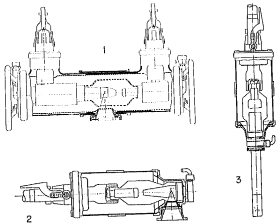


FIGURE 19. PROTECTIVE TUBE HEADS

shown in figure 17. The targets were not cooled and would become white hot during operation. To avoid melting the target, it was necessar to disperse the electrons over a wide area of the target, thus requiring large source sizes. Target design has evolved through the development of massive copper heat absorbers and rotating anodes to the present day system of liquid or gas cooling. The most efficient electron energy conversion is accomplished by using metals of high atomic numbers for target material. Prior to forced cooling systems, tungsten was the compromise between conversion efficiency and high-strength at high temperature. Modern X-ray equipment uses tungsten, gold, and platinum. The shape of the X-ray beam emitted from the target has been the subject of considerable development. As soon as the heat dissipation problem was solved, it was found possible to construct thin targets which would emit X-rays in the forward direction (transmitted beam) as well as to the sides (reflected beam). By selected positioning of the target within the tube structure, almost any beam configuration could be obtained to suit a variety of applications (fig. 18). To restrict the actual radiation developed in the target to its effective beam, it is common design practice to place thick lead absorbers or diaphragms around the tube (fig. 19).

Section II. GAMMA RAY EQUIPMENT DESIGN

18. GENERAL

a. Gamma ray equipment design serves two basic functions. It provides (1) a radiation-safe storage container, and (2) a system for the remote handling of the radioisotope source.

b. The sensitivity of gamma radiography is almost totally contingent upon the radioisotope being used and is dependent only to a small degree upon the design of the storage-handling equipment. Personnel safety, and inspection economics, however, require efficient and safe equipment. The United States Atomic Energy Commission (USAEC) requires that all equipment used to store and handle those radioisotopes which are under their jurisdiction meet with certain standards of safety. The same care must be exercised in designing equipment for use with radium not under USAEC control. The specifics dealing with safety are covered in Chapter 8 of this pamphlet. However, to appreciate the design and functions of equipment a certain amount of the safety design must be mentioned.

19. BASIC DESIGN FOR SAFE STORAGE

To afford protection from gamma radiation when a radioisotope is not in use, advantage is taken of the principle of radiation absorption. A mass of heavy metal, lead or uranium, is fabricated with a passage leading to its geometric center. When the radioisotope is placed at this center, a maximum of protection is achieved. The amount of metal

used is predetermined to reduce the radiation at the surface to a safe level. Innovations of this principle are used to facilitate the various methods of handling. The use of heavy metal is the result of weight-size compromise which gives the required gamma ray absorption. Containers are designed specifically for the maximum of activity of a given radioisotope or combination of radioisotopes.

20. BASIC DESIGN FOR SAFE HANDLING

a. All radioisotopes used in industrial radiography are encapsulated; i.e., contained within a metallic protective housing. This housing is usually a thin stainless steel sheath and is often protected by an aluminum cover. Encapsulation does the following:

(1) Prevents abrasion of radioactive metals such as Cobalt 60.

(2) Prevents spillage of radioactive salts such as Cesium 137 or Radium 226.

(3) Prevents leakage of radioactive gas such as Radon 222 from Radium 226.

(4) Lessens the possibility of loss or accidental mishandling.

(5) Provides a means for attachment of rods and wires used for moving the source.

Encapsulation is accomplished in specially equipped facilities. There is no need for personnel to tamper with this capsule and, in fact, a broken or crushed capsule is cause for grave alarm.

b. Removal of the encapsulated source from the storage container may be accomplished by one of three means according to the design of the system.

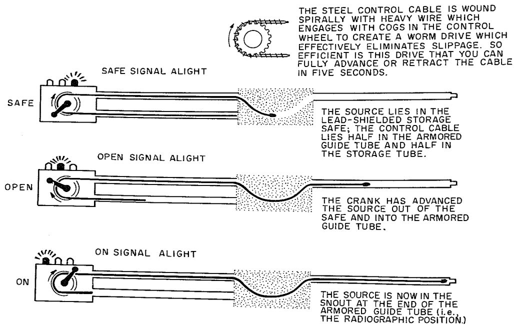


FIGURE 20. CABLE DRIVE SOURCE HANDLING UNIT

cable travel within a plastic covered steel guide tube which both protects the assembly and permits positioning of the source. The container unit has either a "V" - or "S"-shaped passage through which the cable drive can push out or pull back the source. The midpoint of either passage is the maximum safe position. A system of flashing lights operated by microswitches may be used to indicate the location of the source capsule. Another means of showing source position is a length index giving the amount of cable which has passed through the control system. Figure 20 shows a typical cable drive handling unit.

(3) Pneumatic drive handling. The use of a pneumatic drive affords a third means of transferring the source capsule from container to exposure position. Except for the method of propelling the capsule, the general design is very similar to the cable drive system.

c. Some gamma ray equipment does not require the removal of the source from the container. Rather, a cone section of container is designed to swing away permitting the unobstructed escape of radiation. Actuation of the cone, both opening and closing, is accomplished from a safe position behind the container.

21. GAMMA RAY BEAM CONFIGURATION

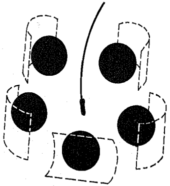
Radioisotope handling equipment can be classified under two categories with respect to the configuration of the gamma ray beam. When the source is removed from the container and placed in a predetermined exposure position, the beam of radiation is emitted in a spherical manner. This is known as panoramic projection and is applicable to multiple exposures (fig. 21). If the source remains in the container and gamma rays are permitted to escape through a designed opening, it is known as conical or directional projection. This method is used when it is desired to reduce the radiation hazard; when radiography is performed in confined quarters; or when extremely active sources are employed. The use of heavy metal absorbers to confine the dimensions of either the projected or panoramic beam is an asset to most gamma ray equipment. The merit of this beam restriction device stems from the reduction of possible radiation hazard to operating personnel and the improvement of radiographic quality brought about by the reduction of scattered radiation.

Section III. SELECTION OF X-RAY EQUIPMENT

22. ANALYSIS OF INSPECTION PROBLEM

a. Prior to selecting X-ray equipment, the job or area of work to be accomplished must be defined. Without this information, a truly economical and technically efficient selection is not possible. The acquisition of X-ray equipment for the inspection of a single item is

a. Panoramic gama radiography



b. Schematic of figure "a" above

FIGURE 21. PANORAMIC GAMMA RADIOGRAPHY

the exception rather than the rule. Generally, inspection requirements fall within a field or area of interest. Also, future planned expansion or diversification must be considered.

b. This type of requirement analysis also applies to the range of tasks to which X-ray equipment might be applied. This range can be usefully expressed in terms of maximum and minimum thicknesses of given materials or components to be inspected. Consideration must also be given to the size and weight of material, the steps in the production process where inspection is best suited, and the quantity to be inspected in a given time.

c. After outlining what items are to be inspected, it is then necessary to consider the types of irregularities to be encountered. The possibility of effectively and economically locating such flaws by radiography will conclude the analysis problem.

d. If the analysis affirms that radiography is the correct inspection method, then effort can be turned to selecting the most suitable X-ray equipment.

23. GENERAL SELECTION OF X-RAY EQUIPMENT

A careful analysis of a radiographic inspection task will provide information that can be applied to the correct selection of X-ray equipment. The thicknesses and types of material to be examined will dictate the necessary X-ray exciting potential to achieve efficient penetration. The type of manufacturing facility and the bulk, weight, and quantity of products will establish the equipment requirements regarding the kind of installation. Table II shows the relationship between radiation energy, expressed in terms of exciting potential, and material thickness (steel). Table III gives general applications for the several categories of equipment according to voltage rating.

24. SPECIFIC SELECTION OF X-RAY EQUIPMENT

a. The general selection of equipment is followed by the problem of choosing a specific X-ray machine. This choice depends upon the radiographic inspection task. Within the requirements established by the analysis of the inspection problem, there must be selected the specific machine which will perform most satisfactorily. Selection will be based upon five principal factors: radiation quality; radiation output; source size; range of operation; and reliability. The last factor, reliability, is beyond the scope of this text. The other factors are worthy of some elaboration.

(1) Radiation quality. The choice is made to attain the optimum compromise between the ease of penetration at higher energies resulting in shorter exposure times, and the greater radiation absorption at lower energies which results in better contrast and improved radiographic quality. When selecting

Table II. RELATIONSHIP BETWEEN VOLTAGE AND STEEL THICKNESS

Voltage	Production Techniques Steel (inches)	Laboratory Techniques Steel (inches)
175 kv	1/8 - 1	1/8 - 1-1/2
250 kv	1/4 - 2	1/8 - 3
1000 kv	1/2 - 4	1/2 - 6
2000 kv	3/4 - 8	3/4 - 10
15 mev	3/4 - 14	3/4 - 18

Table III. RELATIONSHIP BETWEEN VOLTAGE AND APPLICATION

Voltage Rating	General Application
50 kv	Radiography of wood, plastics, textiles, leather, grain; diffraction and micro-radiography.
100 kv	Radiography of light metals and alloys. Fluoroscopy of food stuffs, plastic parts and assemblies, and small light alloy castings.
150 kv	Radiography of heavy sections of light metals and alloys, and of thin sections of steel or copper alloys. Fluoroscopy of light metals.
250 kv	Radiography of heavier sections of steel or copper. Fluoroscopy is not generally used at this voltage.
1000-2000 kv Radioactive Isotopes	Radiography of very heavy ferrous and non-ferrous sections.

X-ray equipment, it is best to obtain a unit which will emit a radiation spectrum containing a large portion of the short wavelengths indicative of the maximum or peak exciting potential. With such a unit, it is still possible to operate at the lower energies to get the longer wavelength X-rays which improve radiographic contrast. However, if the unit does not deliver a good quantity of the more penetrating X-rays indicated by the peak potential rating, the only way to reduce the exposure time is to obtain other equipment of higher exciting potential. To assess the quality of an X-ray source, we must know the characteristic half-value layer which it produces. The half-value layer is that thickness of a given material which will reduce the emitted radiation to one-half the incident amount. When comparing two X-ray machines which are generally equal in design, the machine which produces the larger half-value thickness in a given material is the most efficient.

(2) Radiation output. The conversion of electrons into X-rays is an inefficient process. Over 90 percent of the power consumed by an X-ray machine is wasted in the production and dissipation of heat. This heat problem is a most significant economic factor in the design and construction of X-ray equipment and is directly related to the X-ray output. To reduce heat, the X-ray output is often curtailed. A second factor which influences the X-ray output is the effective potential applied in accelerating the electrons. This is the same characteristic mentioned in connection with the quality of radiation, but it is a different influence of this characteristic. The quantity of X-rays generated increases with the 2.5 power of the exciting potential; i.e., conversion of the electron energy to X-rays becomes more efficient as the exciting potential increases. Therefore, the larger percentage of electrons which are accelerated at the higher or near to peak potential, the greater the output of the X-ray machine. A third factor which affects the output is the quantity of X-rays absorbed in the material of which the machine is constructed. This is termed inherent absorption. To assess the radiation output or productivity from an X-ray machine, we must know the roentgen output. The roentgen output is a measure of the number of X-ray photons developed, based upon the ionization effect produced when these photons are absorbed in air. When comparing two X-ray machines which are generally equal in design, the machine with the highest output in roentgens is the more suitable. For comparison purposes, all factors concerned with the roentgen measurement must be equivalent. Roentgen output is expressed in terms of roentgens per hour at a distance of one meter (rhm).

(3) Source size. For a given quantity of X-rays, the smaller the target area still capable of providing a useful quantity of radiation, the better the sensitivity.

(4) Range of operation. The ability of an X-ray machine to operate efficiently over a range of exciting potentials is a factor of merit. However, the width of the operating range is dictated rather sharply by several factors. For example, the inherent absorption in the X-ray tube walls, and machine housing at low energies requires special design to obtain a useable quantity of radiation. These special features are costly and usually are not required at higher energies. X-ray machines designed to opera at maximum potentials of 150 or 300 kv are generally of limited usefulness below 70 kv. The quantity of radiation which can be obtained at potentials below the peak rating is often extremely limited, and the usefulness of the equipment at lower than rated potentials is questionable. Equipment of good quality is designed with an operating range predicated upon a compromise between technical proficiency and normal application requirements.

b. Table IV provides information concerning the characteristics of different types of X-ray equipment.

Table IV. CHARACTERISTICS OF VARIOUS TYPES OF X-RAY EQUIPMENT

Equipment	Laboratory	Mobile	Enclosure	Portable
Flexibility	Good	Best	Fair	Good
Results Obtainable	Best	Good	Good	Good
Equipment expense	Moderate	High	High	Moderate
Installation expense	High	Low	Moderate	Low
Floor space required	Large	No fixed amount	Small	Low
Protection	Good	Fair	Best	Fair
Maintenance expense	Low	Moderate	Moderate	Moderate
Set-up speed	Moderate	Slow	Fast-adaptable to automatic operation	Slow

Section IV. SELECTION OF GAMMA RAY EQUIPMENT

25. GENERAL

The selection of gamma ray equipment begins with the same requirement as the selection of X - ray equipment : defining the inspection problem. The basic concepts of inspection problem analysis were discussed under X-ray equipment selection and will not be repeated here. Instead, this section will deal with gamma ray equipment on the assumption that radiographic inspection has been determined necessary and the equipment choice lies first, between X-ray and gamma ray equipment, and second, between the several radioisotopes available. With regard to the use of comparable radiation energies, gamma rays may be substituted directly for X-rays with satisfactory results. However, the fact remains that the wider spectrum, and therefore the presence of lower energy radiation obtained from X-ray equipment, usually gives superior sensitivity.

26. GAMMA RAY CONSIDERATIONS

Economics form a basis for the selection of gamma ray over X-ray equipment. The initial cost of gamma ray equipment is generally less and the maintenance is somewhat lower as the equipment is rather simple. The actual maintenance cost is restricted primarily to replacement of the radioisotope source as it weakens through atomic disintegration. The lower radiation intensity as compared to X-rays and the more simplified method of operation often negates the need for special costly installations, especially in the high energy field. However, this same factor, lower radiation intensity, works adversely to increase the inspection time. Gamma ray use approaches its maximum economic efficiency when: the inspection rate is low; the material to be inspected is similar in design and advantage can be taken of the radial, annular emission to make numerous simultaneous exposures; the foreseen extent of the inspection need is short or not predictable. The application of gamma ray radiography to certain specific types of inspection is often based upon convenience regardless of economics. For example, radiography performed in confined areas or inspection of enclosed fabrications such as pipe, tanks, internal ship structures, etc., is suited ideally to the small isotope source in comparison to the more bulky X-ray tube. The absence of power requirements is another factor which lends advantage to isotope use for field inspection.

27. RADIOISOTOPE SELECTION

The selection of a radioisotope for a particular task or area of inspection work is based principally upon two characteristics: radiation energy and source size. The selection of radiation energy is accomplished in the same manner and for the same purpose as with X-ray equipment. Table I gave the approximate equivalents between gamma ray energy and X-ray exciting potential. Consideration of the gamma ray energy

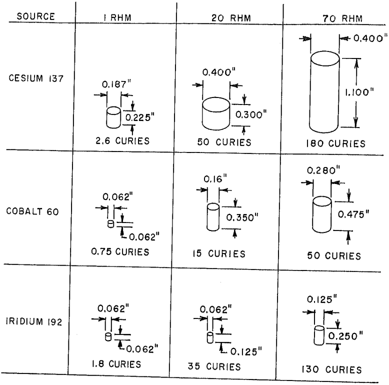


FIGURE 22. TYPICAL SOURCE SIZES AND RHM OUTPUTS

and the data supplied in Table II will guide efforts in such selection. It should be noted that unlike X-ray equipment, there is no range of operation with radioisotopes. This fact requires a greater compromise between penetration time and radiographic sensitivity when using gamma rays. The size of the source available with radioisotopes is determined by the specific activity, i. e., the actual percentage of the element which has been converted into radioisotope; and the quantity of radioisotope involved, i. e., the number of curies. Figure 22 illustrates some representative physical sizes of gamma ray sources with respect to the elements concerned and quantity of activity.

CHAPTER 4

FILM RADIOGRAPHY

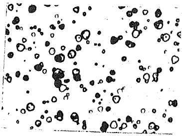
Section I. GENERAL

28. EFFECT OF RADIATION ON FILM

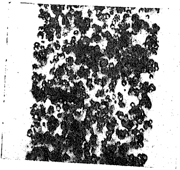
a. To understand the production of an image on X-ray film, it is first necessary to know what an X-ray film is, and what effect radiation and subsequent processing has on it.

b. An X-ray film is basically a sheet of transparent, blue-tinted, cellulose derivative material, coated on either one or both sides with a photosensitive emulsion. This emulsion consists of gelatin in which is dispersed very fine grains of silver halide salts; primarily, silver bromide. The emulsion is about 0.001 inch thick on either side of the film. Figure 23 shows various magnified views of X-ray emulsion.

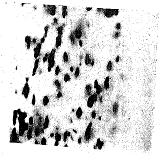
c. The emulsion is sensitive to certain wavelengths of electromagnetic radiation and when exposed to X-, gamma, or visible light-rays, a change occurs in its physical structure. This change is of such a nature that it cannot be detected by ordinary physical methods. When the silver halide grains are exposed to radiation, they become "sensitized." When they are subsequently treated with a chemical solution (developer), a reaction takes place causing the reduction of the silver salts to black, metallic silver. It is this silver, suspended in the gelatin, which constitutes the image. The developing solution is basically a mild alkaline reducing solution containing several additional chemicals to control the speed with which the solution acts and to extend the life of the solution. The film is left in the developer long enough to allow the sensitized grains to be darkened; i.e., reduced to metallic silver. If the film is developed too long, unexposed grains will also be reduced, and the film will be uniformly darkened or "fogged." After the film has been developed, it is placed in a weak acid solution to stop the action of the developing solution. The film is then placed in a fixing bath, commonly called a "hypo," which dissolves all the undeveloped salts and leaves only the metallic silver or dark grains in the emulsion. The "hypo" also contains agents which harden the emulsion to make it more durable. Finally, the film is thoroughly rinsed in running water, to remove all traces of the various solutions, and dried. When the processed film is viewed in front of a strong light, those areas of the film which were not exposed to light or X-rays are transparent, while those areas exposed to X-rays contain metallic silver and are dark or opaque.



a. The silver bromide grains of an x-ray film emulsion (2,500 diameters). These grains have been dispersed to show their shape and relative sizes more clearly. In an actual coating, the crystals are much more closely packed.



b. Cross section of an unprocessed emulsion on one side of an x-ray film (2,000 diameters). Note the large number of grains as compared to the developed grains of Figure c.



c. Cross section (2,000 diameters) showing the distribution of developed silver grains in an x-ray emulsion exposed to give a moderate density.

FIGURE 23. VARIOUS MAGNIFIED VIEWS OF INDUSTRIAL X-RAY FILM EMULSIONS

d. X-ray film is very similar to ordinary photographic film except that it has special characteristics which make it superior for radiographic work. Passable photographs can be made with X-ray film, and photographic film will record an X-ray image, although not as well as X-ray film. Most X-ray films have a response to visible light similar to that of commercial orthochromatic photographic films. Such films are quite sensitive to blue light, but are relatively insensitive to red or yellow light. For this reason, X-ray films may be safely handled in a dark room which is properly illuminated with red or yellow light of low intensity. Several types of "safelights" are commercially available with special filters for use in the processing of X-ray films.

29. COMMERCIAL X-RAY FILMS

a. While a photographic image may be formed by light and other forms of radiation, as well as by X- or gamma rays, the properties of the latter two are of a distinct character and, for this reason, the photosensitive emulsion must be different from that used in other types of photography. In fact, the wide range of conditions and the variety of materials encountered in industrial radiography has led to the development of several specific types of films to meet these diverse requirements.

b. The many factors governing the selection of a particular type, or combinations of types, of X-ray film will be discussed in Section II of this chapter. Basically, however, there are three grades of film for industrial radiography: coarse grain, fine grain, and extra-fine grain film. The fine and extra-fine grain film give the highest contrast or quality, but require relatively long exposure times. The coarser grain films do not quite give the good quality results that the finer grain films do, but they need only relatively short exposure times. A consideration of all the factors involved in radiographing a given item or component determines the choice of film to be used. Since there is a wide variety of films to choose from, the experienced radiographer should have no trouble selecting the correct film for a given job.

c. Commercial X-ray film is sold in two basic forms. The first is sheet film of various standard dimensions which may be coated with the photosensitive emulsion on only one side, but which is normally supplied coated on both sides of the film; the second is roll film of various widths and practically unlimited length. This second form is especially useful for radiographing circumferential areas. In addition to these two basic forms, custom tailored shapes can be supplied by most manufacturers on request.

Section II. FILM EXPOSURE AND PROCESSING TECHNIQUES

30. GENERAL

a. In this section there will be discussed the effect of the many considerations involved in producing the optimum radiograph.

b. Industrial radiography has many diverse applications. In each application, there are many considerations in obtaining the best radiographic results. They include, but are not limited to:

(1) The composition, shape, and size of the part being examined, and, in some cases, the weight and physical location as well.

(2) The type of radiation used, whether X-rays from an X-ray machine, or gamma rays from a radioactive source.

(3) The kilovoltages available with the X-ray equipment, or the quality of the gamma radiation.

(4) The kind of information sought, whether it is simply an overall inspection, or the critical examination of some especially important portion, characteristic, or feature.

(5) The resulting relative emphasis on definition, constrast, density, and the time required for proper exposure.

All of these factors are important in determining the most effective combination of radiographic technique and film.

31. FILM DENSITY AND EXPOSURE

a. Film Density

(1) Film or photographic density refers to the quantitative measure of film blackening, and for radiographic purposes the term "density" alone is generally used. Density is defined as the common logarithm of the ratio of light incident upon one side of a radiograph to the light transmitted through the radiograph. To illustrate: when the silver deposited in the emulsion allows 1/10 of the incident light to pass through the radiograph, the ratio is 10:1. The logarithm of 10 is 1; thus by definition the density is 1. If only 1/100 of the incident light passes through the radiograph, the ratio is 100:1 for which the logarithm and therefore the density is 2. By formula:

$$\text{Density (D)} = \log \frac{I_o \text{ (incident light)}}{I_t \text{ (transmitted light)}}$$

(2) For general radiographic use, a series of films or a film strip exposed to various density levels is sufficient to compare with and thus judge the approximate density of production radiographs. Density standards of this type should be calibrated using a reliable densitometer. Because the den-

ade

b. Exposure

(1) X-ray exposure

(a) Since X-ray output is directly proportional to both milliamperage and time, it is directly proportional to their product. This product is known as the "exposure." It is expressed algebraically as $E = Mt$, where E is the exposure, M the tube current in milliamperes, and t the exposure time in minutes or seconds. Hence, the amount of radiation from a given source will remain constant if the exposure remains constant, no matter how the individual factors of tube current and exposure time are varied. This permits specifying X-ray exposure in terms of milliampere-minutes or milliampere-seconds, without stating the specific values of tube current or time.

(b) The kilovoltage applied to the X-ray tube affects the quality of the X-ray beam. As the kilovoltage is raised, X-rays of shorter wave length, and hence of more penetrating power are produced. Referring back to figures 7 and 8, note that in the higher kilovoltage beam, there are some shorter wave lengths which are absent from the lower kilovoltage beam. Thus, raising the kilovoltage not only increases the penetration, but also increases the intensity, sometimes to a great extent.

(2) Gamma ray exposure

(a) The total amount of radiation emitted from a gamma ray source during a radiographic exposure depends upon the source strength (usually stated in curies or millicuries) and the time of exposure. For a particular radioactive isotope, the intensity of the radiation is approximately proportional to the strength of the source in curies.

(b) The gamma ray output can be assumed to be directly proportional to both source strength and time, and hence directly proportional to their product. Analogous to X-ray exposure, the gamma ray exposure (E) may be stated $E = Mt$, where M is the source strength in curies or millicuries, and t is the exposure time. The amount of gamma radiation will remain constant so long as the product of source strength and time remains constant. This permits specifying gamma ray exposures in millicurie-hours, for example, without stating specific values for source strength or time.

(c) Since gamma ray quality is fixed by the nature of the particular radioactive isotope, there is no variable to correspond to the kilovoltage factor encountered in X-radiography.

(d) A gamma source is constantly losing strength; therefore a correction must be made in order that the correct strength (in curies) is used. The frequency of correction depends upon the rate at which strength is lost (half life). For radium, the half life is so long that correction is not required. For artificially induced isotopes, the original strength and date of conversion is furnished by the USAEC. The strength for any subsequent time can be readily calculated, knowing the original strength and half life of the isotope.

32. FILM CHARACTERISTIC CURVES

a. The characteristic curve, sometimes referred to as the sensitometric or H and D curve (after Hurter and Driffield), expresses the relationship between the exposure applied to a photographic film and the resulting photographic density. Such curves are obtained by giving a film a series of known exposures, determining the densities produced by such exposures, and then plotting density against the logarithm of relative exposure. Figure 24 shows the characteristic curves of two typical films.

b. Relative exposure is used because there are no convenient units suitable to all kilovoltages and scattering conditions, in which to express radiographic exposures. Hence, the exposures given a film are expressed in terms of some particular exposure, thus giving a relative scale. The use of the logarithm of the relative exposure, rather than the relative exposure itself, has a number of advantages. It compresses an otherwise long scale. Furthermore, in radiography, ratios of exposures are usually more significant than the exposures themselves. Pairs of exposures having the same ratio will be separated by the same interval on the log relative exposure scale, no matter what their absolute value may be. Consider the pairs of exposures given in table V.

Table V. SOME RELATIVE EXPOSURE RELATIONSHIPS

Relative Exposure	Log Relative Exposure	Interval in Log Rel. Exp.
1)) 5)	0.0)) 0.70)	0.70
2)) 10)	0.30)) 1.00)	0.70
30)) 150)	1.48)) 2.18)	0.70

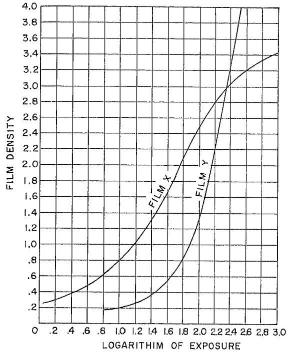


FIGURE 24. CHARACTERISTIC CURVES FOR TWO FILM TYPES

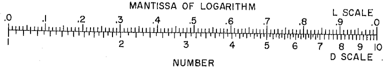


FIGURE 25. SCALE FOR DETERMINING LOGARITHMS

c. Referring to figure 25, notice that the antilogarithm of 0.70 comes out to be approximately 5.0 which is also the ratio of each pair of exposures. Therefore, to find the ratio of any pair of exposures, it is necessary only to find the antilog of the log E (logarithm of relative exposure) interval between them. Conversely, the log exposure interval between any two exposures is found by taking the logarithm of their ratio.

d. The slope, or steepness of the characteristic curve for X-ray film, changes continuously along its length. The density difference corresponding to a difference in specimen thickness depends on the region of the characteristic curve on which the exposures fall. The steeper the slope of the curve in this region, the greater will be the density difference, and hence the greater will be the visibility of detail.

e. The slope of a curve at a particular point may be expressed as the slope of a straight line drawn tangent to the curve at that point. Where applied to the characteristic curve of a photographic material, the slope of such a straight line is called the gradient of the material at the particular density. A typical characteristic curve for a radiographic film is shown in figure 26. Tangents to the curve have been drawn at two points, and the corresponding gradients (ratio a/b, a'/b') have been evaluated. Note that the gradient varies from 1.0 in the toe (lower portion of the curve) to much greater than 1.0 in the high-density region.

f. Now consider slightly different thicknesses in a specimen. These will transmit slightly different intensities of radiation to the film; i.e., there will be a small difference in the logarithm of the relative exposure to the film in the two areas. Assuming that at a certain kilovoltage the thinner section transmits 20 percent more radiation than the thicker section, then the difference in logarithm of relative exposure (Δ log E) will be 0.08, and will be independent of milliamperage, exposure time, or source-film distance. If this specimen is now radiographed with an exposure which puts the developed densities on the toe of the characteristic curve where the gradient is 0.8, the X-ray intensity difference of 20 percent is represented by a density difference of 0.06 (fig. 27). If the exposure is such that the densities fall on that part of the curve where the gradient is 5.0, the 20 percent intensity difference results in a density difference of 0.40.

g. In general, then, if the gradient of the characteristic curve is greater than 1.0, the intensity ratios, or subject contrasts, of the radiation emerging from the specimen are amplified in the radiographic reproduction, and the higher the gradient, the greater is the degree of amplification. Thus, at densities for which the gradient is greater than 1.0, the film acts as a "contrast amplifier." Similarly, if the gradient is less than 1.0, subject contrasts are effectively diminished in the radiographic reproduction.

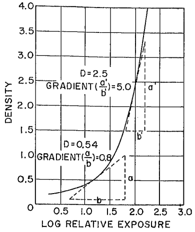


FIGURE 26. TYPICAL CHARACTERISTIC CURVE FOR A RADIOGRAPHIC FILM

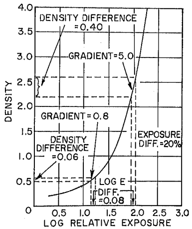


FIGURE 27. CHARACTERISTIC CURVE FOR A RADIOGRAPHED SPECIMEN SHOWING DENSITY DIFFERENCES

h. A minimum density is often specified for radiographs. This is not because of any virtue in a particular density, but rather because o the gradient associated with the density. The minimum useful density is that at which the minimum useful gradient is obtained. In general, gradients lower than 1.0 should be avoided whenever possible.

i. The ability of a film to amplify the subject contrast is of the utmost importance. Otherwise, many small differences in the subject could not be made visible. This gain in contrast is utilized in practically all industrial radiography. It is especially significant in radiography with very penetrating radiations which produce low subject contrast. High radiographic contrast depends greatly on the enhancement of subject contrast by the film.

j. It is often useful to have a single number to indicate the contrast property of a film. This need is met by a quantity known as the averag gradient, defined as the slope of a straight line joining two points of specified densities on the characteristic curve. In particular, the specified densities between which the straight line is drawn may be the maximum and minimum useful densities under conditions of practical use. The average gradient, then, will indicate the average contrast properties of the film over this useful range. For a given film and development technique, the average gradient will, of course, depend upon the density range chosen. In cases where high-intensity illuminators are available and high densities are used, the average gradient calculated for the density range 1.0 to 4.0 will represent the contrast characteristics fairly well. If high densities are for any reason not to be used, a density range of 0.5 to 2.5 is suitable for evaluation of this quantity. Figure 28 shows the characteristic curve of one type of industrial X-ray film. The average gradients for this film over both the above density ranges are indicated.

k. Experiments have shown that the shape of the characteristic curve is, for practical purposes, independent of the quality of X- or gamma-radiation. Therefore, a characteristic curve made with any radiation may be applied to exposures made with any other, and the same is true of values of gradient or average gradient derived from the curve.

l. The influence of kilovoltage or gamma ray quality on contrast in the radiograph, therefore, is due primarily to its effect upon the subject contrast, and only very slightly, to any change in the contrast characteristics of the film. Radiographic contrast can also be modifiec by choice of a film of different contrast, or by use of a different density range with the same film. Contrast can also be affected by the degree of development, but, in industrial radiography, films are developed to their maximum, or nearly maximum contrast. In the early stages of development, both density and contrast increase quite rapidly with time of development. However, with about 5 minutes development at 68°F (20°C) in fresh developer or developer plus replenisher, most of the available density and contrast have been attained. With the

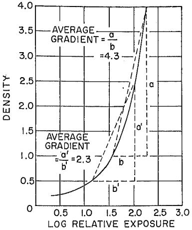


FIGURE 28. CHARACTERISTIC CURVE FOR ONE TYPE OF INDUSTRIAL X-RAY FILM

direct X-ray film types, approximately 30 percent more speed, and in some cases, slightly more contrast can be gained by developing for 8 minutes.

m. A special case arises when, for technical or economic reasons, there is a maximum allowable exposure; i.e., exposure time cannot be increased to take advantage of the higher film gradient at higher densities. In such a case, an increase in kilovoltage will increase the radiation intensity penetrating the specimen, and hence cause the film to be exposed to a higher density. This may result in an increase in radiographic contrast in spite of the lowering of the subject contrast. An example may be taken from the exposures used to produce the exposure chart of figure 29. Table VI lists the densities obtained through 1/2 and 5/8-inch sections of steel using an exposure of 9.6 milliampere-seconds.

Table VI. RELATIONSHIP BETWEEN KILOVOLTAGE, DENSITY, AND CONTRAST AT EXPOSURE TIME

KV	Density (A) 1/2" Steel	Density (B) 5/8" Steel	Radiographic Contrast (A-B)	Relative Radiographic Contrast
120	0.57	0.32	0.25	20
140	1.23	0.66	0.57	47
160	2.49	1.50	0.99	81
180	3.74	2.52	1.22	100

n. It can be seen that, with the exposure time fixed, the density difference between the two sections increases, and hence the visibility of detail in this thickness range is also increased, as the kilovoltage is raised. The increase in visibility of detail occurs in spite of the decrease in subject contrast occasioned by the increase in kilovoltage, and is the direct result of using higher densities, where the film gradient is higher. Qualitatively, the film contrast is decreasing as a result of increased kilovoltage. It should again be emphasized that this change in radiographic contrast with kilovoltage is not the result of a change in characteristic curve shape, but rather the result of using a different portion of the characteristic curve; a portion where the slope is greater.

33. FILM SPEED

a. It has been shown that the contrast properties of a film are governed by the shape of the characteristic curve. The other significant value obtained from the characteristic curve is the relative speed, which is governed by the location along the log E axis of the curve in relation to the curves of other films.

b. Speeds of radiographic films are usually given as inversely proportional to the exposure required to achieve a certain density. Further, since there are no units of X-ray exposure conveniently applicable to industrial radiography, speeds are expressed in terms of one particular film, whose relative speed is arbitrarily assigned a value of 100.

c. In figure 30, the curves for various films are spaced along the log relative exposure axis. The spacing of the curves arises from the differences in relative speed; the curves for the faster film lying to the left of the chart, those for the slower films lying toward the right. From these curves, relative exposures to produce a fixed density can be determined, and the relative speeds will be inversely proportional to these exposures. For most industrial radiographic purposes, a density of 1.5 is an appropriate level at which to compute relative speeds, although where all work is done at high densities and the radiographs are viewed on high-intensity illuminators, a density of 2.5 is more suitable. Relative speed values, derived from figure 30, for the two density levels are given in Table VII. Note that the relative speed computed at the two densities are not the same, a result of the differences in curve shape from one film to another. As would be expected from looking at figure 30, this is most noticeable for Type F Film.

Table VII. RELATIVE SPEEDS AND EXPOSURE VALUES DERIVED FROM FIGURE 30

Film	Density = 1.5		Density = 2.5	
	Relative Speed	Relative Exposure to give D = 1.5	Relative Speed	Relative Exposure to give D = 2.5
Type M	40	17	45	14
Type AA	170	4	170	4
Type F	250	3	170	4
Type K	700	1.0	650	1.0
No-Screen	550	1.3	530	1.2

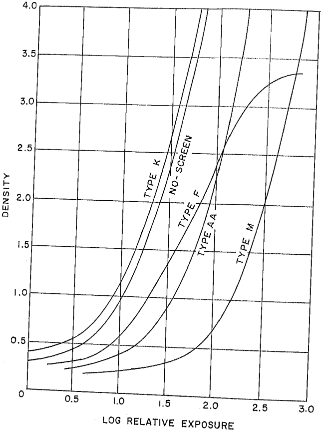


FIGURE 30. CHARACTERISTIC CURVES FOR VARIOUS TYPES OF FILMS

d. Although the shape of the characteristic curve of a film is practically independent of changes in radiation quality, the location of the curve along the log relative exposure axis, with respect to the curve of another film, does depend on radiation quality. Thus, if curves of the type shown in figure 30 were prepared at a different kilovoltage, the curves would be differently spaced; i. e., the film would have different speeds relative to the film which had been chosen as a standard of reference. This difference is attributed primarily to the efficiency of radiation absorption of a film at different energy levels.

34. THE RECIPROCITY LAW

a. It has been assumed in the preceding discussions that the exact compensation for a decrease in exposure time could be made by increasing the intensity of the radiation. A radiographer therefore could reduce exposure time by 20 percent, if he increased the radiation intensity an equal amount by either shortening the source-film distance or increasing the output of the X-ray source. This direct compensation is termed the reciprocity law and is valid when using direct X-ray or lead screen exposure techniques. Stated mathematically, for a given exposure (E), the values of intensity (I) and time (t) can be varied at will if their product (I x t) is not changed.

b. The reciprocity law fails when fluorescent screens are used. This failure is due to the radiographic film emulsion which is sensitive not only to the amount but also the brightness of the light. Therefore, when exposure time is increased and radiation intensity decreased, the fluorescent screens will emit the same total amount of light, but over a longer time and at a lower brightness level. The effect of this lower brightness will be less exposure to the radiograph. The decrease in film exposure (density) will be small and cause little difficulty until the X-ray intensity is altered considerably. When the X-ray intensity is altered by a factor of 4 or more, it will be necessary to change the total exposure inversely by approximately 20 percent to compensate for this deviation from the reciprocity law.

c. In radiography, marked changes in an established exposure technique are effected very readily by changing the source-film distance and by taking advantage of the inverse square law effect. When this action is taken and fluorescent screens are being used, the failure of the reciprocity law can be mistaken for a failure of the inverse square law.

35. TECHNIQUE CHARTS

a. Some variables associated with radiography are predictable and can be calculated. One variable, the radiation energy spectrum developed by an X-ray machine, is not readily predictable. Because this spectrum dictates the penetrating quality of the emitted X-rays, the techniques used with any X-ray machine vary, and require special attention. Such attention usually takes the form of developing data

which is pertinent to radiographing various materials and thicknesses of these materials with a particular machine. Such data, when in convenient form, expedites the selection of correct techniques. The general techniques published by X-ray machine vendors are only approximate and seldom satisfactory for direct application.

b. Industrial radiographic techniques should be based upon the sensitivity required to discern the probable or expected flaws. Because of this fact, technique charts should be designed as plots of either intensity-time or material thickness at a given radiation energy. A radiographer then selects the lowest energy which will provide an economical exposure for a given thickness. The most appropriate manner in which to develop technique charts is outlined as follows:

(1) Subdivide the working range of the X-ray machine into convenient and useful levels determined by the type of work to be accomplished. For example:

(a) Light alloy radiography with an X-ray machine having a range of 60 to 140 kvp subdivided into five levels; 60-80-100-120-140 kvp.

(b) Steel radiography with an X-ray machine having a range of 50 to 300 kvp, subdivided into six levels; 50-100-150-200-250-300 kvp.

(2) Develop a step-type specimen wherein the thickness progresses in increments convenient to the material and process of manufacture to which the intended radiography will apply. For example, when the products of a fabricator vary between 1/8 and 1-1/4 inches in thickness, the step-typo specimen would be constructed using 1/8-inch plates. Stacking of plates should allow a sufficient area for each thickness to give a clear image, free of edge effects created by geometric overlay and scattered radiation. Although not necessary, the inclusion of penetrameters on each thickness is helpful in judging final results.

(3) For each of the selected energies, a series of exposures are made using convenient periods of time and the maximum intensity of radiation available from the source. The convenience of the time periods will depend largely upon the type of material involved and the energy of radiation used. The source-subject/subject-film distance (d/t) ratio should be commensurate with good definitive quality and may require change of the distances used (but never the ratio) when the thicknesses involved cover a considerable range. Typical time periods would be minutes (1, 2, 4, etc.) and seconds (15, 30, 45 and 60). The magnitude of exposure change should be sufficient to obtain equivalent density on the next greater thickness. The number of exposures made should be confined to reasonable times as would be used in production.

(4) The radiographs obtained will give information regarding exposures of thickness for a given radiation energy, film system, set-up geometry, and material. Each exposure will represent the product of time and intensity of radiation (milli- or microamperes). Each exposure will also illustrate the density range (latitude) which can be expected with the technique used. Several methods of graphing this data are possible. Figure 31 shows a number of radiation energies plotted on a single chart. Figure 32 shows a single radiation energy plotted to indicate the latitude of density obtained.

(5) The basic information may be modified to suit desired changes in technique without redoing all of the exposures. For example:

(a) The change in exposure required by the use of a different film may be calculated and a second set of exposure values developed and applied to the same graph.

(b) The change in exposure required by a change in d/t ratio can be computed through use of the inverse square law and a second set of exposure values developed for the same curve.

(c) A technique chart for a new alloy (of the same base material) can be developed by making a single exposure at a given thickness and comparing the density thus obtained with the original alloy. The original curve may then be shifted vertically to indicate the technique for the new

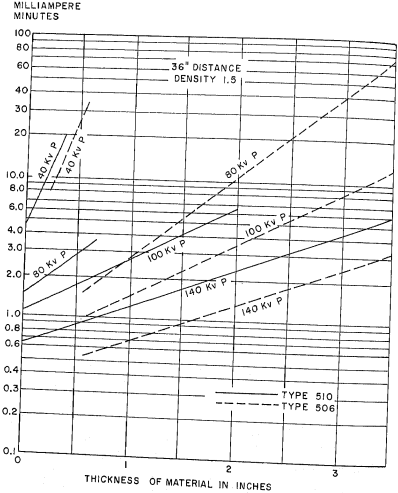


FIGURE 31. TECHNIQUE CHART: TIME AND INTENSITY VS THICKNESS OF MATERIAL (MAGNESIUM) AT SEVERAL ENERGY LEVELS

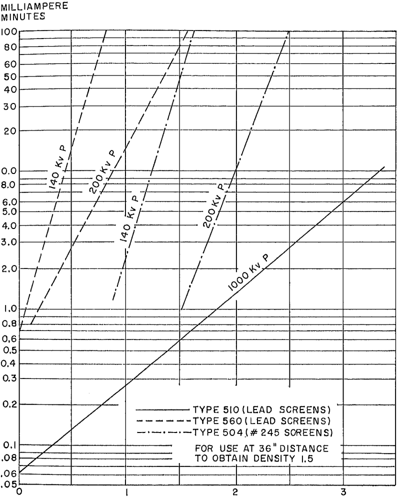


FIGURE 32. TECHNIQUE CHART: TIME AND INTENSITY VS THICKNESS OF MATERIAL (STEEL) AT CONSTANT POTENTIAL

fully utilizing this wasted energy, without complicating the technical procedure, is highly desirable. Two types of radiographic screens (lead foil and fluorescent) are used to achieve this end.

b. Lead Foil Screens.

(1) Lead foil placed on both sides of a film has a desirable effect upon the quality of the radiograph. In radiography with gamma rays and X-rays below 2,000 kv, the front lead foil need only be 0.004 to 0.006 inch thick; consequently, its absorption of the primary beam is not serious. The back screen, however, should be thicker to reduce back-scattered radiation. Such screens are available commercially. The choice of lead screen thicknesses in multimillion volt radiography is much more complicated, and the manufacturer of the equipment should be consulted for recommendations.

(2) Lead foil in direct contact with the film has three principal effects:

(a) It increases the photographic action on the film, largely by reason of the electrons emitted and partly by the secondary radiation generated in the lead.

(b) It absorbs the longer wavelength scattered radiation more than the primary.

(c) It intensifies the primary radiation more than the scattered radiation.

The differential absorption of the secondary radiation and the differential intensification of the primary radiation result in diminishing the effect of scattered radiation, thereby producing greater contrast and clarity in the radiographic image. This reduction in the scattered radiation decreases the total intensity of the radiation reaching the film and thereby apparently lessens the net intensifying factor of the screens. The absorption of primary radiation by the front lead screen also diminishes the net intensifying effect, and, if the incident radiation does not have sufficient penetrating power, the actual exposure required may be even greater than without screens. At best, the exposure time is one-half to one-third that without screens. The advantage of the screens in reducing scattered radiation, however, still holds.

(3) The quality of the radiation necessary to obtain an appreciable intensification from lead screens depends upon the type of film, the kilovoltage, and the thickness of the material through which the rays pass. In the radiography of aluminum, for example, the thickness must be about 6 inches, and the

voltage as high as 120 kv, to secure any advantage in exposure time with lead screens. In the radiography of steel, lead screens begin to give appreciable intensification with steel thicknesses in the neighborhood of 1/4 inch and at voltages of 130 to 150 kv. In the radiography of 1-1/4 inches of steel at 200 kv, lead screens permit an exposure of about one-third that without screens (i.e., an intensification factor of 3). With gamma rays, the intensification factor of lead screens is about 2. Lead foil screens, however, do not detrimentally affect the definition or graininess of the radiographic image to any appreciable degree, providing the lead foil and film are in intimate contact.

(4) Lead foil screens diminish the effect of scattered radiation, particularly that which undercuts the object when primary rays strike the portions of the film holder or cassette outside the area covered by the object.

(5) Scattered radiation from the specimen itself is cut almost in half by lead foil screens, contributing to maximum clarity of detail in the radiograph; this advantage is obtained even under conditions where the lead screens make necessary an increase in exposure. For a more complete discussion of scatter, see par. 14h.

(6) In radiography with gamma rays or high voltage X-rays, films loaded in cassettes without screens are apt to record the effects of secondary electrons generated in the lead-covered back of the cassette. These electrons, passing through the felt pad on the cassette cover, produce a mottled appearance due to the structure of the felt. Films loaded in the customary lead-backed cardboard exposure holder may also show a pattern of the structure of the paper which lies between the lead and the film (fig. 33). To avoid these effects, the film should be enclosed between double lead screens, care being taken to insure good contact between film and screens. Thus, lead screens are essential in practically all radiography with gamma rays or millionvolt X-rays. If, for any reason, screens cannot be used with these radiations, the film should be loaded in a lightproof paper or cardboard holder, without any metal backing.

(7) Contact between the film and lead foil screens is essential to good radiographic quality. Areas in which contact is lacking produce fuzzy images as shown in figure 34.

(8) Lead foil screens must be selected with extreme care. Commercially pure lead is satisfactory. An alloy of 6 percent antimony and 94 percent lead, being harder and stiffer, has better resistance to wear and abrasion. Tin-coated lead foil should be avoided, since irregularities in the tin cause

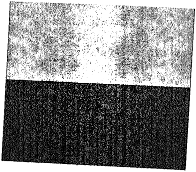


FIGURE 33. EFFECT OF FOREIGN MATERIAL BETWEEN LEAD SCREEN AND FILM. UPPER AREA SHOWS DECREASED DENSITY CAUSED BY PAPER BETWEEN LEAD SCREEN AND FILM. AN ELECTRON SHADOW PICTURE OF THE PAPER ALSO SHOWS.

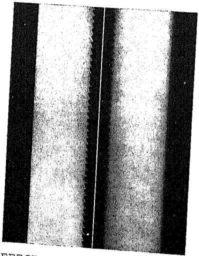


FIGURE 34. EFFECT OF CONTACT OF LEAD FOIL SCREEN AND FILM ON IMAGE SHARPNESS. GOOD CONTACT GIVES A SHARP IMAGE (LEFT). POOR CONTACT RESULTS IN A FUZZY IMAGE.

variations in the intensifying factor of the screen, resulting in mottled radiographs. Minor blemishes do not affect the usefulness of the screen, but large blisters or cavities should be avoided.

(9) Most of the intensifying action of a lead foil screen is caused by the electrons emitted under X-ray or gamma ray excitation. Because of the high electron absorption of light materials, the surface must be kept free of grease and lint which will produce light marks on the radiograph. On the other hand, deep scratches on lead foil screens will result in dark lines. Grease and lint may be removed from the surface of lead foil screens with a solvent. If more thorough cleaning is necessary, screens may be very gently rubbed with fine steel wool. If this is done carefully, the shallow scratches left by the steel wool will not show up as dark lines on the radiograph.

(10) Films may be fogged if left between lead screens longer than is reasonably necessary, particularly under conditions of high temperature and humidity. When screens have been freshly cleaned with an abrasive, this effect will be increased; hence, prolonged contact between film and screens should be delayed at least 24 hours after cleaning.

c. Fluorescent Screens

(1) Certain chemicals fluoresce, that is, have the ability to absorb X-rays and gamma rays and emit light. The intensity of the light emitted depends upon the intensity of the incident radiation. The compounds most commonly used for intensifying screens are calcium tungstate and barium lead sulfate. They are finely powdered, mixed with a suitable binder, and coated in a thin, smooth layer on a special cardboard support to form a screen.

(2) For the exposure, the film is placed between a pair of these screens. The photographic effect on the film, then, is the sum of the effects of the X-rays and of the light emitted by the screens. A few examples will serve to illustrate the importance of intensifying screens in the reduction of exposure time. In the radiography of 1/2 inch steel at 150 kv, the exposure is about 1/125th as much with screens as without them. That is, the intensification factor is as high as 125. In the radiography of 3/4 inch steel at 180 kv, intensification factors of several hundred have been achieved experimentally. At this latter condition, the intensification factor has about reached its maximum and it diminishes both for lower voltage and thinner steel, and for higher voltage and thicker steel. Using radium or Cobalt 60 gamma rays for very thick steels, the factor may be 10 or less.

(3) Intensifying screens may be needed in the radiography of steel thicknesses, greater than 1-1/2 inches at 200 kv, 3 inches at 400 kv, and 5 inches at 1,000 kv.

(4) Fluorescent intensifying screens are not generally used with gamma rays, since they tend to give excessive graininess to the image, and since failure of the reciprocity law (par. 34) results in relatively low intensification factors with the long exposure times usually necessary in gamma ray radiography. For the radiography of light metals, fluorescent screens are rarely necessary; but, should they be required, the best choice would be fluorescent screens of a type designed specifically for sharpness of definition and the reproduction of fine detail at relatively low kilovoltages.

(5) At kilovoltages higher than those necessary to radiograph about 1/2 inch of steel, the graininess associated with the intensifying screen is largely independent of screen type. Therefore, in such cases, the fastest available screens should be used, since the major use of fluorescent intensifying screens is to minimize exposure time.

(6) Normally, fluorescent screens are used with film having the highest sensitivity to the blue light which they emit. There are certain cases, however, in which a speed intermediate between the maximum and that obtainable with lead foil screens would be useful. In this case, a high-speed, coarse grain, medium contrast film may be used with fluorescent screens. The speed will be about one tenth that obtained with the previously mentioned film (a slower speed, coarse grained, medium contrast film); however, the contrast and maximum density will be higher, and the graininess associated with the fluorescent screen will be much less apparent.

(7) Fluorescent intensifying screens are usually mounted in pairs in rigid holders, called cassettes, so that the fluorescent surface of each is in direct contact with one of the emulsion surfa... of the film. Intimate contact of the screens ... their entire areas is essential, because poor ... the fluorescent light to spread and produce ...ge, as shown in figure 35a.

...e, the mounting is done by the film vendor who is equipped to provide this service in accordance with the manufacturer's recommendations. If the screens are mounted by the purchaser, care must be exercised to avoid physical unevenness that would result from any thick or uneven bonding material. The adhesive must not cause discoloration of the screens, as even a small degree of discoloration will reduce their effective speed. In addition, the choice of the adhesive is important; it must not cause fogging of the film.

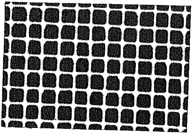
(9) Fluorescent light from intensifying screens obeys all the laws of visible light and cannot pass through opaque bodies, as do X-rays. To prevent extraneous shadows caused by absorption of the fluorescent light by foreign matter during exposure, dust and dirt particles must not be allowed to collect between film and screen surfaces, and stains upon the screens must be avoided. Cleanliness of the order desirable for handling film and screens is sometimes difficult to maintain, but much can be done by stressing its need and eliminating carelessness.

(10) It is desirable that fluorescent screens never by subjected to the full intensity of an X-ray beam while making a radiograph. If the specimen more than covers screen area, or if proper masking is provided, there is practically no danger of causing discoloration of the screen, or of producing afterglow, from excessive exposure.

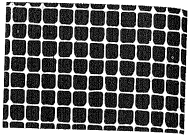
(11) As a matter of routine, all cassettes should be periodically tested to check on the contact between the screens and the film. This can be easily done by securing a piece of wire screening (any size, and mesh, from 1/16 inch to 1/2 inch is satisfactory) and mounting it so that it lies fairly flat. The cassette is then loaded with film, the wire screening placed on the exposure side of the cassette, and a flash exposure made. If there are poor contact areas, the result will be as shown in figure 35a. If there is proper contact, the shadow of the wire mesh will be outlined sharply, as in figure 35b.

(12) Fluorescent intensifying screens may be stored in the processing room but away from chemicals and other sources of contamination. The sensitive surfaces should not be touched, because the image of finger marks and dust particles may show in the radiograph and interfere with accurate interpretation. Fluorescent screens usually have a transparent protective coating. This coating reduces the abrasion of the active surfaces and facilitates the removal of dirt and smudges from the screens. Every effort should be made to avoid soiling fluorescent screens. Should they become soiled, they must be carefully cleaned according to the manufacturers' recommendations. Hydrogen peroxide or other common cleaning agents should never be used for this purpose, because their chemical composition may cause fogging of the sensitive film emulsions.

(13) The use of thin cellulose sheets for protecting the active surface of intensifying screens is particularly objectionable, because any seperation between screen and film has an adverse effect on radiographic definition. Also, under dry atmospheric conditions, merely opening the cassette is



a. Fuzzy image produced by poor contact



b. Sharp image produced by good contact

FIGURE 35. EXAMPLE OF IMPORTANCE OF GOOD CONTACT BETWEEN FILM AND SCREEN

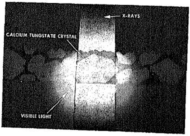


FIGURE 36. SPREADING OF VISIBLE LIGHT BEYOND THE X - RAY BEAM WHEN FLUORESCENT SCREEN IS EXCITED

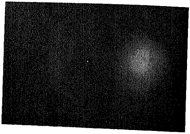


FIGURE 37. LOW DENSITY AREA ON FILM CAUSED BY PRESSURE MARK

liable to produce static electrical discharges between the sheets and the film. The result will be tree-like black markings in the radiograph.

(14) The advantage in using fluorescent intensifying screens lies in the great reduction in exposure time that their use permits. As a corollary to this, the radiography of relatively thick specimens on X-ray units of moderate power is facilitated. For instance, using fluorescent screens, 3 inches of steel may be radiographed at 250 kv with a reasonable time exposure.

(15) Fluorescent screens give poorer definition in the radiograph, compared to a radiograph made directly or with lead foil screens. For this reason, they are seldom used except when economy demands the shorter exposure times their use allows. The poorer definition results from the spreading of the fluorescence emitted from the screens as shown in figure 36. The light from any individual crystal spreads out beyond the confines of the original X-ray beam which excites the crystal to fluorescence. The overlapping of many such minute areas accounts for the blurring of outlines in the radiograph.

(16) If a general rule can be given, it is that fluorescent screens should be used only when the exposure time necessary without them would be prohibitive.

d. Cassettes and Film Holders

(1) When intensifying or lead foil screens are used, good uniform contact between screens and film is of prime importance. The use of vacuum cassettes or of rigid, springback cassettes is the most certain way to obtain such intimate contact. If rigid cassettes are tested for screen contact at reasonable intervals, no further attention need be given the matter.

(2) Cardboard or thin plastic holders are cheaper, easier to handle in large numbers, and are flexible as compared to rigid cassettes. However, if screens are to be used in them, special precautions must be taken to insure good contact. The exact means used will depend upon the object being radiographed. Exposure holders may be pressed or clamped against the specimen, or the weight of the specimen or the flexing of the holder as it is bent to fit some structure, may provide adequate contact.

(3) Two points should be noted, however. First, these methods do not guarantee uniform contact, and hence the definition of the image may vary from area to area of the film. This variation of definition may not be obvious and may cause

errors in the interpretation of the radiograph. Second, such holders do not always adequately protect the film from mechanical damage. A projection on the film side of the specimen may cause a relatively great pressure on a small area of the film. This may produce, in the finished radiograph, a light or dark pressure mark (fig. 37) which may be mistaken for a flaw in the specimen.

37. FILM PROCESSING AND CONTROL

a. General. In processing film, the latent image produced by exposure to X-rays, gamma rays, or light, is made visible and permanent. Processing is carried on under subdued light, or a color to which the film is relatively insensitive. The film is first immersed in a developer solution which causes the areas exposed to radiation to become dark, the amount of darkening for a given degree of development depending upon the degree of exposure. After developing, the film is rinsed, preferably in an acid bath. To stop development, the film is next put into a fixing bath, which dissolves the undarkened portions of the sensitive silver salts, and then is washed to remove the fixing chemicals and dissolved salts.

b. General Considerations

(1) Tank processing

(a) In this system, the processing solutions and wash water are contained in tanks deep enough for the film to be suspended vertically. This method has several advantages: the processing solutions have free access to both sides of the film; the temperature can be controlled by regulating the water in which the processing tanks are immersed; and the system is economical of space, and is also time saving (fig. 38).

(b) The exposed film is mounted on a hanger immediately after it is taken from the cassette or film holder (figs. 39 through 41), to insure that it will be held securely and taut throughout the course of the processing.

(c) At frequent intervals during the processing, films must be agitated. Otherwise, the solution in contact with the emulsion becomes exhausted, affecting the rate and evenness of development or fixing. Also, the level of the developer solution must be kept constant by adding fresh solution or replenisher. This addition is necessary to replace the solution absorbed by the dry film when they are first immersed.

(d) Figure 42 illustrates the step-by-step procedure used for tank processing of X-ray films.

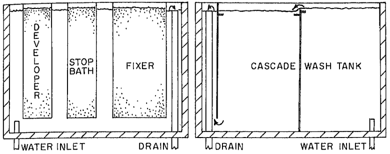


FIGURE 38. TANK TYPE FILM PROCESSING UNIT

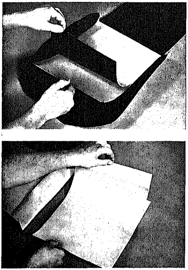


FIGURE 39. METHOD OF RE-
MOVING FILM FROM X - RAY
EXPOSURE HOLDER

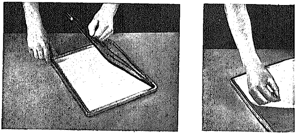


FIGURE 40. METHOD OF REMOVING FILM FRC

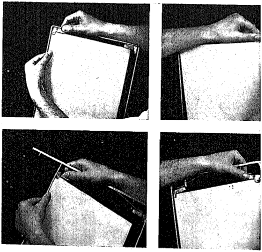


FIGURE 41. METHOD OF FASTENING FIL
ON DEVELOPING HANGER

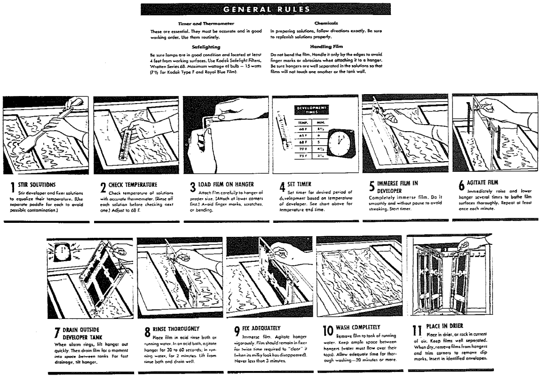


FIGURE 42. STEP-BY-STEP PROCESSING OF FILM

(2) Machine processing. Where the volume of work is large, automatic processing machines may be used to reduce the darkroom manpower required. Processing machines move films through the various solutions according to a predetermined schedule. Manual work is limited to the routine of loading and unloading the machine.

(3) Cleanliness. In handling X-ray films, cleanliness is a prime essential. The processing room, as well as the accessories and equipment, must be kept scrupulously clean and used only for the purposes for which they are intended.

(4) Mixing processing solutions. Processing solutions should be mixed according to manufacturer's instructions, and the procedures outlined should be followed carefully. The mixing vessels or pails should be made of stainless steel, enamelware, glass, hard rubber, or glazed earthenware. (Metals such as aluminum, galvanized iron, tin, copper, and zinc can cause contamination of the solutions with subsequent fogging in the radiographs.)

c. Development.

(1) Developer Solutions. Developers recommended for industrial radiography are available in two forms: powders and liquids. They are comparable in performance and effective life, but the liquid offers greater convenience in preparation. Normal development time for X-ray films in these solutions is 5 minutes at 68°F (20°C).

(2) Importance of standardized developing procedure.

(a) The time-temperature system of development should be used in all radiographic work. In this system, the developer is always kept within a certain small temperature range and the development time adjusted according to the temperature in such a way that the degree of development remains the same. If this procedure is not carefully observed, the effects of even the most accurate exposure technique will be nullified. Films cannot withstand the effects of errors resulting from guesswork in processing. In particular, "sight development" should not be used. That is, the development time for a radiograph should not be decided by examining the film under safelight illumination at intervals during the course of development.

(b) An advantage of standardized time-temperature processing procedure is that a definite check on exposure time can always be made, thereby precluding a large percentage of errors that might otherwise occur.

(c) For example, the image recorded in the film emulsion by correct exposure will usually be fully developed and present the normally desired contrast and density after the film has remained for the specified time (with occasional agitation) in a fresh solution of developer, at the optimum temperature; normally 68°F (20°C). However, if the processing factors are correct and the radiographs are found to lack density, it can be assumed that the film was underexposed; if the radiographic image is too dense, overexposure is indicated. The first condition can be corrected by increasing the exposure time and the second, by decreasing it; to be appreciable, any change should be an increase of the original time factor by at least 40 percent.

(3) Control of temperature and time. The temperature of the processing solutions has a decided influence on their activity; hence, careful control of this factor is very important. The temperature of the developer solution should be checked immediately before films are immersed. The temperature should be 68°F (20°C). Below 60°F (16°C), the action of the chemicals is retarded and is likely to result in underdevelopment, whereas an excessively high temperature may not only destroy the photographic quality by producing fog, but also may cause frilling or may soften the emulsion to the extent that it will wash off the base. If it is not feasible to maintain the solutions at 68°F (20°C), the development time should be changed as indicated in table VIII.

Table VIII. TIME-TEMPERATURE COMPENSATION

Developer Temperature Degrees F.	Development Time in Minutes Slow, Medium-Slow, Fast and No-Screen Films	
	Normal	Maximum
60	8 1/2	16
65	6	10
68	5	8
70	4 1/2	7
75	3 1/4	5 1/2

(4) Agitation. It is essential to secure uniformity of development over the whole area of the film. This is achieved by agitating the film during the course of development. Figure 43 illustrates the phenomena which occurs when a film, having small areas whose densities are widely different from their surroundings, is developed without any agitation of film or developer.

(5) Activity of developer solutions.

(a) As a developer is used, its developing power decreases partly because of the destruction of the developing agent in changing the exposed silver salts to metallic silver, and also because of the restraining effect of the accumulated reaction products. The extent of this decrease in activity will depend upon the number of films processed and their average density. Even when the developer is not used, the activity may decrease slowly because of oxidation of the developing agent.

(b) To compensate for decreasing developing power, the solution should be maintained by suitable chemical replenishment.

(c) It is not practical to continue replenishment indefinitely and the developer should be discarded when the quantity of replenisher used equals two to three times the original quantity of developer. In any case, the solution should be discarded at the end of three months because of oxidation, and the accumulation of gelatin, sludge, and mechanical impurities that find their way into the solution.

(6) Testing developer activity.

(a) The easiest way to test developer activity is to process, at frequent intervals, film strips cut from a sheet of film, 8 by 10 inches or larger, which has been exposed to direct X-rays through a stepped wedge (fig. 44), and to compare the densities obtained with an identical strip that has been processed in the fresh solution. The wedge should have about 15 steps and be large enough to cover completely the largest cassette or film holder used. When given the proper exposure, this should produce a series of densities extending over the density range used in practice.

(b) The stepped-wedge method of testing developer activity is also useful in cases where the temperature of the processing solutions cannot be exactly controlled.

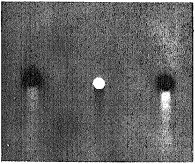


FIGURE 43. FILM STREAKING

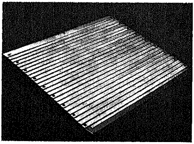


FIGURE 44. STEP WEDGE

Strips are developed for a series of times, and the development time which gives a strip matching the one developed at 68°F (20°C) in the fresh solution is used for routine work.

d. Arresting Development.

(1) When development is complete, the films should be removed from the developer, allowed to drain for 1 or 2 seconds, and then be immersed in an acid stop bath to arrest developer activity. The developer draining from the films should be kept out of the stop bath. Instead of draining, a few seconds' rinse in fresh, running water may be used prior to inserting the films in the stop bath. This will materially prolong the life of the bath.

(2) If a stop bath cannot be used, a rinse in running water for at least two minutes should be used. It is important that the water be running and that it be free of silver or fixer chemicals. This means that the tank used for final washing after fixing should not be used for this rinse.

e. Fixing the image.

(1) General.

(a) The purpose of fixing is to remove all of the undeveloped silver salts of the emulsion, thereby leaving the developed silver as a permanent image. The fixer has another function of hardening of the gelatin so that the film withstands subsequent drying. The fixing time in a relatively fresh fixing bath should, in general, not exceed 15 minutes; otherwise, some loss of low densities may occur.

(b) The films should be agitated vigorously when first placed in the fixer, and at least every 2 minutes during the course of fixing. This will insure uniform action of the chemicals. The exact fixing time for X-ray films depends upon the type and number of films processed, the type (manufacturer's brand) and condition of the fixing solution, and the temperature of the bath. Roughly, the time of fixing for small batches of film (0-50) in a bath maintained at 68°F (20°C) is from 3 to 10 minutes. The fixing bath should be maintained at the same temperature as the developer; ideally, between 65°F (18°C) and 70°F (21°C), and in any event not over 75°F (24°C).

(2) Activity of fixer solutions. During use, the fixer solution accumulates soluble silver salts which gradually inhibit

its ability to dissolve the unexposed silver salts from the emulsion. Also, the fixer solution becomes diluted by rinse water or stop bath carried over to it by the film. As a result, the rate of fixing decreases, and the hardening action is impaired. This dilution can be partially prevented by thorough draining of films before their immersion in the fixer, and, if desired, the fixing ability can be restored by replenishment of the fixer solutions.

f. Washing.

(1) X-ray films should be washed in running water so circulated that the entire emulsion area will receive frequent changes. For proper washing, the bar of the hanger and the top clips should always be covered completely by the running water.

(2) Efficient washing of the film depends both on a sufficient flow of water to carry the fixer away rapidly, and on adequate time to allow the fixer to diffuse from the film; the hourly flow of water should be from 4 to 8 times the volume of the tank; the time of rinsing should follow manufacturers' recommendations.

g. Drying.

(1) Where only a small number of films are processed daily, racks for holding hangers during drying are commercially available. The films should be suspended to obviate the danger of striking the radiographs while they are wet, or spattering water on the drying surfaces, which would cause spots on them. Radiographs dry best in warm, dry air that is changing constantly.

(2) Where a considerable number of films are to be processed, suitable dryers with built-in fans, filters, and heaters or desiccants are commercially available.

h. Filing Radiographs. After the radiograph is dry, it is prepared for filing by trimming the pointed corners and the sharp projections that are caused by the film-hanger clips. When the corners have been trimmed, the radiographs should be placed in a heavy manila envelope of proper size, and all of the essential identification data should be written on the envelope, so it can be easily handled and filed.

38. FILM DEFECTS

a. Defects, spots, and marks of many kinds occur if the preceding general processing rules are not carefully followed. Perhaps the most common processing defect is a streakiness or mottle in areas which received a uniform exposure. This unevenness may be a result of:

(1) Failure to agitate the films sufficiently during processing.

(2) The use of too many hangers in a tank resulting in inadequate spacing between films.

(3) Insufficient rinsing between processing steps.

(4) The use of depleted solutions.

b. Other characteristic marks are: (1) dark spots caused by the spattering of developer solution, static electric discharges, and finger marks; and (2) dark streaks occurring when the developer-saturated film is inspected for a prolonged time before a safelight lamp. When it is possible to avoid it, films should never be examined at length until they have been dried.

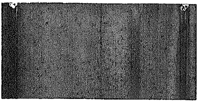
c. Fog is an undesirable development of silver salts due to causes other than those affected by radiation during exposure and is a great source of annoyance. It may be caused by accidental exposure to light, X-rays, or radioactive substances; contaminated developer solution; development at too high a temperature; or by keeping films under improper storage conditions or beyond its normal shelf life. A common occurrence is accidental exposure of the film to X-radiation, because of insufficient protection from high-voltage tubes; films have been fogged through 1/8 inch of lead in a room 50 feet or more from the tube.

d. Figure 45 shows typical film defects resulting from improper handling or processing of X-ray films.

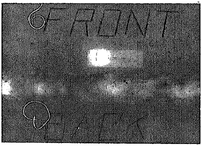
39. THE PROCESSING ROOM

a. The location, design, and construction of the X-ray processing facilities are major factors in the installation of adequate radiographic services. The facilities may be a single room, or a series of rooms for individual activities, depending upon the amount and character of the work performed. Because of the special importance of these rooms for the handling, processing, and storing of X-ray films, both their general and detailed features should be most thoughtfully worked out. When planning reflects care and foresight, the effort expended is soon offset by ease of operation, improved production, and low maintenance costs.

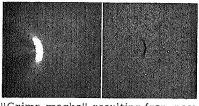
b. The flow of X-ray films from the radiographic room, through the processing facilities, to the viewing room should be a simple yet smooth operation requiring the fewest possible steps and unnecessary motions. The routine can be expedited by properly planning the location within the department of the room or rooms devoted to processing, and by efficient arrangement of equipment.



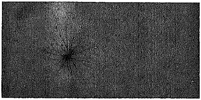
The use of hangers which have not been adequately washed free of processing solution can cause severe streaks on the next films developed with such hangers. Continuation of such practice may so contaminate the developer that stained radiographs and shortened developer life result.



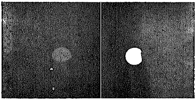
The words "Front" and "Back" were scratched in the surface of front and back lead foil screens before radiographing a 1 - inch welded steel plate. Hairs placed between the respective screens and the film show as light marks preceding the scribed words.



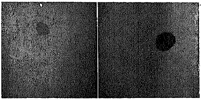
"Crimp marks" resulting from poor handling of individual sheets of film before exposure (left) and after exposure (right).



Static marks resulting from poor film - handling technic. Static marks may also be treelike or branching.



Light spots are caused by stop bath (left) or fixer (right) splashed on film before development.



Dark spots are caused by water (lef or development (right) splashed on film before development.

FIGURE 45. TYPICAL FILM DEFECTS CAUSED BY IMPROPER PROCESSING

CHAPTER 5

OTHER RADIOGRAPHIC TECHNIQUES

Section I. FLUOROSCOPY

40. GENERAL

a. Fluoroscopy is the conversion of X-ray patterns to visible light. Direct fluoroscopy is relatively fast and inexpensive and is in widespread use despite certain disadvantages. It is generally used to scan a product for gross internal discontinuities or abnormal conditions.

b. The advantages of this inspection system are:

(1) An instantaneous visualization of the X-ray shadowgraph.

(2) The cost of inspection is materially less than radiography when calculated on a per unit basis.

(3) The system is fast and can be easily adapted to factory production lines.

(4) Operators are easily trained.

c. The disadvantages of this inspection system are:

(1) It gives relatively poor sensitivity.

(2) It depends greatly on human vision.

41. FLUOROSCOPIC COMPONENTS

a. The limitation of fluoroscopy can best be understood by analyzing the components of a fluoroscopic system. The principal parts of a fluoroscopic unit are: (1) X-Ray Generator; (2) X-Ray Sensitive Screen; and (3) X-Ray Barrier.

b. Test brightness is the direct function of X-ray intensity at a given kilovoltage. This characteristic limits the image contrast of fluoroscopy to something less than that obtained with industrial film, since the film responds to X-rays on a logarithmic scale.

c. Tests have been conducted which indicate there is no advantage in half-wave equipment over a full-wave generator. The eye sees average light and integrates the illumination from the screen over a

given time interval. Because of this characteristic and the fast response of the screen in following the frequency of the X-ray cycle, there is no advantage in either pulsed or constant potential X-ray equipment for fluoroscopic generators. Incidentally, since X-ray energy at the screen determines its brightness, radioisotopes have not been successfully applied to fluoroscopy.

d. Fluoroscopic sensitivity is a function of X-ray image contrast and the resolving power of the entire system. The resolving power of fluoroscopy is a function of the screen grain size and the geometry. Figure 46 shows the minimum defect visible for various X-ray tubes on the same screen. This data is calculated by an empirical formula based on the unsharpness of the fluoroscopic image. A reduction in focal spot size improves the sensitivity within limits if this magnification is used correctly.

e. A reduction of inherent filtration in the X-ray beam improves the contrast and increases the brightness. This effect is most easily seen on light alloy materials with an equivalent thickness less than one-half inch of aluminum. For thicker sections of aluminum, the advantage of the beryllium window is reduced because of the absorption of radiation in the object.

f. The response of fluoroscopic screens to various X-ray voltages indicates a peak at approximately 100 kvp. Figure 47 indicates the relative brightness of various commercially available screens versus peak kilovolts. This accounts for the ineffective application of fluoroscopy at voltages above 160 kvp. The curves also indicate the difference in light output of screens due to the grain size. In effect, the larger the grain size the greater the light output and the poorer the resolving power.

g. Fluoroscopic screens are available with a grain size which will allow a presentation of approximately one to two lines per millimeter. This compares with approximately 30 to 40 lines per millimeter with radiography, using lead screens and a high speed film. Because of this screen characteristic, the only alternative for improvement of sensitivity is by magnification of the image produced by a small focal spot X-ray tube. The low light output of the fluoroscopic screen and the relatively large grain size continue to be a limitation of industrial fluoroscopy.

h. The sensitivity of the fluoroscopic inspection has been the limiting factor in its universal application. In general, with standard equipment, a sensitivity of six to eight percent is obtained. screens and tubes with small focal spots of less than one sensitivities of three percent have been reported.

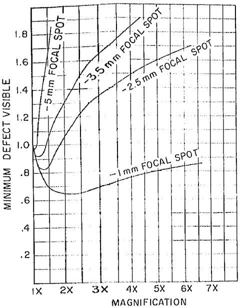


FIGURE 46. MINIMUM DEFECT VS MAGNIFICATION FOR VARIOUS SIZE FOCAL SPOTS

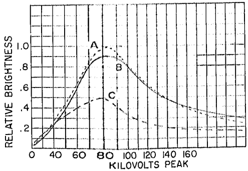


FIGURE 47. RELATIVE BRIGHTNESS VS KILOVOLTS PEAK FOR VARIOUS SCREENS

42. VISUAL ASPECTS

a. The eye is the sole registering medium in fluoroscopy, and as a registering device lacks accuracy. Vision is a variable thing considered from the standpoint of a single individual and is much more of a variable when considered from the standpoint of a number of individuals.

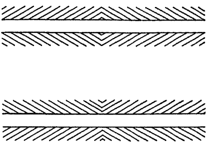
b. In figure 48 the horizontal lines are straight and parallel. The diagonal lines cause an entirely different visual effect. From this it will be seen that vision is not reliable in its recording of shapes and distances. The configuration and surroundings may alter the visual impression.

c. A bright object or area appears brighter when viewed against a dark field. Conversely, the object will appear darker than it really is when the surrounding area is comparatively brighter. This is demonstrated in figure 49 in which the "V" on the left is actually the same brightness as that on the right. These, and many other illusions, must be recognized in any fluoroscopic evaluation.

d. The human eye must accommodate itself to the brightness of illumination to see effectively. This accounts for the seeming blindness experienced when entering an area of subdued lighting from bright sunlight. To accomplish this accommodation there is probably no substitute for total darkness. Fluoroscopy should not be attempted until the operator has spent at least 20 minutes in total darkness. If dark-adaption takes place in other than total darkness, an even longer period of time is necessary. If a period of 20 minutes or more could be spent in the developing room, this could serve as the dark-adaption period.

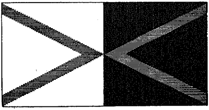
e. In any task requiring critical examination, we are usually more conscious of size than any other factor. The minimum size of an object that can be seen under a given set of conditions is called the threshold size. This varies greatly, depending on brightness-contrast between the immediate background and the detail being examined. It also varies with the level of brightness. For a given viewing distance, the visual size is maximum when the line of sight is perpendicular to the plane in which the object lies. For a 45° angle, assuming an object of fixed physical size and fixed viewing distance, visibility equal to that of 90° can be had only by increasing the illumination level by 2-1/2 times. This can be translated into fluoroscopic factors by an increase of 2-1/2 times in tube current.

f. At ordinary daylight brightness levels, most individuals have no difficulty in distinguishing brightness differences between adjacent areas where these differences are as small as two percent. As the brightness decreases below daylight levels, the minimum perceptible differences become greater and variations between individuals become more pronounced. As the brightness level gets lower and lower, the difference in brightness levels must be greater and greater if the eye is to detect



The horizontal lines are straight and parallel. The diagonal lines cause an entirely different visual effect.

FIGURE 48. OPTICAL ILLUSION



A bright object appears brighter when viewed against a dark field. The V on the left is actually of the same brightness as that on the right.

FIGURE 49. BRIGHTNESS EFFECT

a difference. A contrast of 30 to 100 percent must be present to be readily visible at brightness levels used in fluoroscopy.

Section II. TELEVISION RADIOGRAPHY

43. GENERAL

a. The need for an increase in brightness of the X-ray fluoroscopic image has long been recognized. This problem is unusual in that a minimum gain is sufficient. Once this gain is exceeded, the only possible limit on the detail is then set by the X-ray beam itself. A general figure for this gain in response sensitivity appears to be close to 100 times. Any increase above this factor merely makes for more comfortable viewing of the image by the eye.

b. Various approaches have been made to the problem of X-ray image intensification. One of these is the use of television pick-up or electronic scanning methods. This approach is capable of supplying sufficient gain so that the information contained in the X-ray quanta itself becomes the limiting factor. The following paragraphs will describe a typical system in use today.

44. THE X-RAY SENSITIVE TELEVISION IMAGING SYSTEM

a. An X-ray sensitive closed-circuit television system for the inspection of missile case walls and weldments has been developed. The use of closed-circuit television for X-ray imaging has the advantages of instantaneous image reproduction, and of protection for observing personnel from exposure to ionizing radiations. An instantaneous viewing system of X-ray images permits considerable reduction in production inspection costs. Film radiography, which has been the ultimate method for visualizing an X-ray image, has the advantage of high resolution and contrast sensitivity, but the disadvantage of being time-consuming and expensive. The television X-ray image system provides images equivalent to best fine-grain radiographic film. This system uses a small-diameter X-ray sensitive television camera tube to detect X-radiations which penetrate the object under inspection (fig. 50). With a small-diameter camera-tube sensing area and the large-diameter picture-tube screen, the X-ray image is magnified by an amount equal to the ratio of their respective diameters.

b. The X-ray-sensing camera tube (fig. 51) is similar in physical size and appearance to the conventional photoconductive vidicon tube. Special window and target materials have been employed to provide the desired response to the penetrating radiation. Tubes have been built with glass windows of various thicknesses, and with beryllium windows. Beryllium window tubes have shown much more sensitivity than glass-window tubes because of the inherent transparency of beryllium to X-rays. Tube windows of 0.090 to 0.065 inch thick glass have

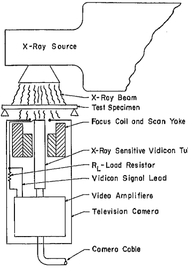


FIGURE 50. RELATIVE POSITIONS OF X - RAY SOURCE, TEST SPECIMEN, AND TELEVISION CAMERA

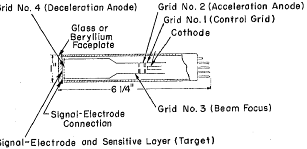


FIGURE 51. X - RAY SENSING CAMERA

been used. The tube transforms the X-ray image into an electrical signal in a manner similar to that by which the light sensitive vidicon tube transforms an optical image into an electrical signal.

c. The system is ideally suited to the inspection of electronic-printed board assemblies. Small components magnified 30 times are easily visualized on the television screen. Conditions such as solder porosity, lack of solder in terminals, porosity in semiconductors, contamination of diodes, partially broken wires, and breaks in copper conductors on printed-circuit boards are easily visualized. Other small enclosed assemblies, such as wrist watches or relays, can be inspected to observe the movement of gears, springs, ratchets, and contacts. Material thicknesses are limited to 1/2 inch of steel.

Section III. XERORADIOGRAPHY

45. GENERAL

a. Xeroradiography is a combination of X-radiography and electrostatics. The X-ray equipment supplies the rays necessary to penetrate the part, and electronic equipment prepares the plate to record this penetration for study and interpretation. The recording plate consists of a backing, usually aluminum, which has been given a coating of amorphous selenium. In the dark, this selenium coating will accept and hold an electrostatic charge, but when exposed to light or radiation the charge decays. The rate of decay is proportional to the intensity of the radiation to which it is exposed. This sensitivity to radiation produces the X-ray picture on the charged plate.

b. Figure 52 illustrates a typical xeroradiography installation. Figure 53 shows a sample xeroradiograph. Figure 54 illustrates the various steps involved in making a xeroradiograph.

46. PROCEDURE

The following procedure is used in making a xeroradiographic image:

a. A selenium-coated aluminum plate is put in a frame to give it body, make it easier to handle, and to provide an easy method of holding the cover slide. This assembly, without the cover slide, is put in a charging frame. Then, a charging bar is passed over the plate, spraying an electron charge on the selenium surface. The cover slide is put on, and the plate assembly is ready for a picture.

b. The assembly is used exactly like an X-ray film cassette. The X-rays pass through the part being tested and the cover slide, to expose the plate by decaying the charge on it. The thickness and density of the part tested regulates the amount and intensity of the radiation reaching the plate. The amount of charge left on the plate is proportional to the intensity of the X-ray penetration.

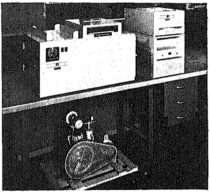


FIGURE 52. TYPICAL XERORADIOGRAPHIC INSTALLATION

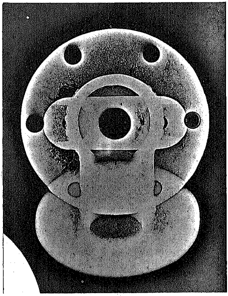
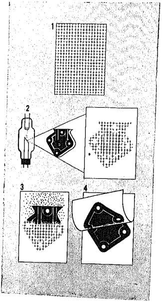


FIGURE 53. SAMPLE XERORADIOGRAPH



1. Aluminum plate coated with photoconductive amorphous selenium is sensitized by receiving positive charge.
2. X-rays penetrate specimen as in conventional radiography. Charge on Xeroradiographic plate leaks away almost proportionately to degree of X-radiation to which it is exposed, leaving a latent electrostatic image.
3. Latent image is rendered visible by negatively-charged powder which adheres to positively-charged areas. Density varies with amount of charge. Image can be viewed directly, copied on film record, or "printed" on paper.
4. Print can be made by pressing special plastic-coated paper on plate by rollers. Powder from plate is transferred, providing positive image, fixed permanently by applying heat. Image on plate can be "erased" in a simple cleaning unit after which it is ready for re-use.

FIGURE 54. PROCESSING OF XERORADIOGRAPH

c. After exposure, the latent image is rendered visible by dusting with a negatively-charged powder which is attracted to the positively-charged areas. The charged areas of the plate attract the powder in proportion to the amount of charge remaining, and so present a picture of the part. The powder prevents further exposure to light and consequent decay of the remaining charge when the plate is removed from the developing unit.

d. The developed picture is interpreted the same as an X-ray or fluoroscope indication. The plate must be handled carefully to prevent anything from touching its surface and disturbing the powder. To provide a permanent record a print can be made by pressing a special plastic-coated paper on the plate with rollers. Powder from the plate is transferred, providing a positive image. This image is fixed permanently by applying heat.

e. After the plate has served its purpose, it is brushed clean of powder so that it can be recharged and reused. To help get rid of any residual charge and the holdover image, the plate is put in a special unit which discharges or relaxes it.

47. UNDERCUTTING

Undercutting is one of the exposure problems encountered in xeroradiography. This is caused by ionization in the air space between the cover slide and the plate. During exposure, discharge occurs at varying rates over the plate surface. This causes discharge patterns that create small electrical eddies. To eliminate this, a d-c voltage is applied between the cover slide and the plate to attract negative ions to the cover slide.

Section IV. STEREORADIOGRAPHY

48. GENERAL

a. Objects viewed with a normal pair of eyes appear in their true perspective and in their correct spatial relation to each other largely because of man's natural stereoscopic vision; each eye receives a slightly different view and the two images are combined by the brain to give the impression of three dimensions.

b. A single radiographic image does not possess perspective. Therefore, it cannot give the impression of depth, or indicate clearly the relative positions of various parts of the object along the direction of vision. The stereoscopie method, designed to overcome this deficiency of a single radiograph, requires two radiographs made from two positions of the X-ray tube, separated by the normal interpupillary distance. They are viewed in a stereoscope, a device which, by an arrangement of prisms or mirrors, permits each eye to see but a single one of the pair of stereoradiographs. As in ordinary vision, the brain

fuses the two images into one in which the various parts stand out in striking relief in their true perspective and in their correct spatial relation.

c. The radiograph exposed in the right-shift position of the X-ray tube is viewed by the right eye, and the one exposed in the left-shift position is viewed by the left eye. In fact, the conditions of viewing the radiographs should be exactly analogous to the conditions under which they were exposed; the two eyes take the place of the two positions of the focal spot of the X-ray tube, and the radiographs, as viewed in the prisms or mirrors, occupy the same position with respect to the eyes as did the films with respect to the tube during the exposures. The eyes see the X-ray representation of the part just as the X-ray tube "saw" the actual part (fig. 55).

d. The stereoscopic method is not often utilized in industrial radiography, but occasionally it can be of considerable value in localizing defects, or in visualizing the spatial arrangements of hidden structures.

49. DOUBLE EXPOSURE (PARALLAX) METHOD

a. Figure 56 gives the details of the double exposure (parallax) method. Lead markers (M_1) and (M_2) are fastened to the front and back, respectively, of the specimen. Two exposures are made, the tube being moved a known distance (a) from (F_1) and (F_2) between them. The position of the images of the markers (M_2) will change very little, perhaps imperceptibly, as a result of this tube shift, while the shadows of the flaw and marker (M_1) will change position by a larger amount.

b. If the flaw is sufficiently prominent, both exposures may be made on the same film. (One exposure "fogs" the other, thus interfering somewhat with the visibility of detail.) The distance of the flaw above the film plane is given by the equation

$$d = \frac{bt}{a+b}$$

where d = distance of the flaw above the film plane

a = tube shift

b = change in position of flaw image

t = focus-film distance

c. If the flaw is not sufficiently prominent to be observed easily when both exposures are made on the same film, two separate radiographs will be necessary. The shadows of the markers (M_2) are

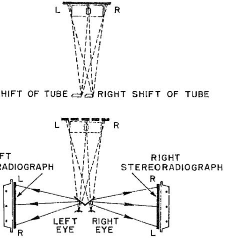


FIGURE 55. STEREOSCOPIC RADIOGRAPHY

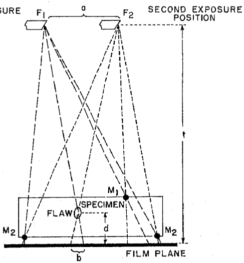


FIGURE 56. PARALLAX TECHNIQUE

superimposed and the shift of the flaw image is measured. The equation given in the preceding paragraph is then applied to determine the distance of the flaw from the film.

d. Often, it is sufficient to know which of the two surfaces of the part the flaw is nearer to. In such cases, the shifts of the images of the flaw and marker (M_1) are measured. If the shift of the flaw image is less than one half the shift of marker (M_1), the flaw is nearer the film plane; if greater than one half, it is nearer the plane of marker (M_1).

Section V. NEUTRON RADIOGRAPHY

50. GENERAL

Neutron radiography is not a common radiographic technique but it does have certain applications and seems to hold promise for increased use in areas which do not normally lend themselves to other means of inspection. For example, a neutron radiograph has been made of a piece of waxed string in a two-inch thick lead block.

51. NEUTRON SOURCES

Although there are many source variations possible, the different types of neutron sources can be conveniently grouped as (1) radioactive sources, (2) accelerators, and (3) nuclear reactors. To obtain good image resolution, the source should originate from a small area or have enough intensity so that objects can be radiographed with a considerable distance between source and film in a reasonable time. The source should also provide a uniform intensity over the desired inspection area. A further requirement is that the radiation beam should not contain a masking radiation (i.e., alpha, beta, or gamma radiation). Particularly, the ratio of gamma to neutron radiation should be low.

52. UTILIZING NEUTRON RADIATIONS

a. Generally, neutrons, fast or slow, have little effect on normal photographic emulsions. The detection techniques which have been used usually make use of some intermediate material which is placed next to the photographic emulsion and which emits some photographically detectable radiation when acted upon by neutron radiation. Materials which have been used for such neutron intensification (i.e., conversion) screens include lithium or boron in conjunction with fluorescent materials (emits alpha and visible light rays), cadmium (emits gamma rays), and silver, iridium, and gold (beta emitters).

b. Work to date has shown the feasibility of using neutron radiography for high-density materials which are relatively opaque to X-

rays, for low density materials relatively transparent to X-rays, and for materials composed of elements having similar atomic weights.

Section VI. FLASH RADIOGRAPHY

53. GENERAL

The development of flash radiography makes it possible to inspect high speed events in opaque materials. This type of inspection is primarily in support of development efforts such as gathering information relative to ballistic, explosive, or rupture processes.

Equipment is available which is capable of producing 10^7 roentgens per second (at tube surface) in short bursts on the order of 0.2 microseconds and at energies of 300 kv. Similar equipment is designed for operating at energies as high as 600 kv. Electrons are obtained via a cold cathode using the field emission principle, and the accelerating potential is built up and released in a burst of energy. Power dissipation reaches several hundred megawatts with a current flow of between one and two thousand amperes. Effective focal spot sizes are on the order of several millimeters wide and generally have a length several times greater than their width. Although the X-rays are developed in fractional microsecond bursts and therefore are capable of arresting motions having velocities of many thousand feet per second, the recycling time is normally several minutes which precludes effective cine-radiography. However, several such X-ray tubes positioned correctly can be pulsed sequentially to obtain progressive information.

CHAPTER 6

RADIOISOTOPE OR GAMMA RADIOGRAPHY

Section I. GENERAL

54. GENERAL

a. The development of industrial radiography has centered around such available radiation sources as X-ray machines and radium. However, not all the smaller foundries and manufacturing facilities can afford this equipment. Radioisotopes of certain of the elements, because of their low cost and wide energy range, have to a large extent displaced radium as a radiographic energy source. Radioisotopes are inexpensive when compared with the cost of equivalent X-ray equipment. It should be pointed out that the sensitivity of radiographs made using X-rays is superior to the sensitivity of those made using radioisotopes, but, there are many applications where sensitivity requirements can be met using radioisotopes. It therefore behooves engineering and inspection personnel to become familiar with the more common radioisotopes available.

b. Prior to the development of the atomic reactor, radium was the main source of radiation used in gamma radiography. Radium, however, was very scarce and very expensive. Now, many different low-cost radioisotopes are available. These isotopes are by-products produced in atomic reactors.

55. PROPERTIES OF GAMMA RADIATION

a. Since radioisotopes emit gamma rays, it would be well to discuss some of the properties of these rays. Gamma rays are penetrating rays of nuclear origin. They differ from X-rays only in their origin and, therefore, have the same valuable characteristics as X-rays. Their wavelengths are about the same as X-rays produced by one and two million volt units. The intensity of gamma rays is proportional to the size or volume of the source. Doubling the source size will double the intensity of the rays. The intensity is also called the specific activity and is measured in millicuries. One millicurie is equal to the intensity of gamma rays emitted by one-milligram of radium.

b. The chief characteristics of gamma rays which are of particular interest in industrial radiography are listed below; gamma rays are:

(1) Differentially absorbed by all material.
(2) Capable of ionization.

(3) Capable of blackening photographic film.
(4) Propagated in straight lines and not affected by electric or magnetic fields.

56. ABSORPTION AND SCATTERING

a. Gamma rays behave the same as X-rays when they strike an object. Some of the gamma radiation will pass through the object, some will be absorbed, while some will be scattered. The absorption of the gamma rays will depend on the same factors that influence absorption of X-rays, namely:

(1) The atomic number of the material.
(2) The density of the material.
(3) The thickness of the material.
(4) The wavelength of the radiation.

b. An increase of any of these factors will result in an increase of the amount of radiation absorbed. Scattering occurs in the same manner as it does with X-rays, but, since gamma rays have high penetrating power, there is little scattering.

57. IONIZATION

Gamma rays in their interaction with matter produce ionization; that is, particles of matter that have a plus or minus charge. This is one means by which radiation is detected and measured. If a volume of gas is enclosed and radiation allowed to fall upon it, some of the electrons are knocked away from an atom so that there are free electrons available. If these electrons are attracted to a positively charged anode, which may be located centrally in the volume of gas, there will be a current flow. Current flow indicates the amount of radiation incident upon the volume of gas. This method of detection is used in ionization chambers.

58. FILM BLACKENING BY GAMMA RAYS

Gamma rays cause film blackening very much like X- and light rays. When film is exposed to gamma rays, a latent image is produced. Upon development, the latent image is made visible. The film characteristic and development procedure is treated in Chapter 4.

59. OTHER CHARACTERISTICS

Two other characteristics enable gamma radiography to be carried out under almost any environmental conditions. Local electric or magnetic fields have no effect on gamma radiation. The propagation of radiation in straight lines allows the arranging of the exposure in the simplest possible geometrical arrangement; gamma source-object-film in a line.

60. ISOTOPES

a. Elements with the same atomic number but with different atomic weights are called isotopes. Some isotopes are stable; others are unstable, or radioactive. For instance, carbon has an atomic weight of 12. An isotope called Carbon 14 is two units heavier than ordinary carbon. Carbon 14 is also radioactive and is called a radioisotope. With the exception of the two differences just mentioned, Carbon 14 and Carbon 12 are identical.

b. A radioisotope is one in which the nuclei of the atoms disintegrate. The disintegration (decay) of the nuclei proceeds with the emission of alpha or beta particles; accompanying the decay, generally with the beta particle, is a gamma ray. It is those isotopes that emit gamma rays that are of value in radiography.

61. PRODUCTION OF ISOTOPES

a. Isotopes are produced by bombarding the atoms of an element with neutrons. The first isotopes were produced in the 1930's by a unit called the Cyclotron. The Cyclotron is a device that shoots neutrons into the atoms of an element at tremendously high speeds. The neutrons strike the nuclei with such force that the structure of the element is changed. Sometimes this change will produce an entirely different element. This process is called transmutation and was the goal of alchemists who tried to convert different materials to gold. The Cyclotron, however, was a slow method of producing isotopes. The neutron flow in an atomic reactor is many times that produced in a Cyclotron. Since the spaces between atoms are vast compared to the size of a neutron, many millions of neutrons must be forced to flow each second. Today, isotopes in large quantities are produced as by-products of the atomic reactors.

b. The element to be activated is first placed in the reactor so that it will be exposed to the neutron stream. There are then three possible reactions that may occur. One process is for the neutron to be absorbed as it strikes the nucleus. This will produce an isotope that is heavier than the original element. Another possibility is that the speeding neutron will knock some fragments out of the nucleus as they collide. This will produce an isotope that is lighter than the original element. The third process is called fission (the splitting of an atom). If U-235 is bombarded with neutrons, it (the U-235) will split and produce two lighter isotopes. Not all isotopes will emit gamma rays; therefore, only the more common ones used in radiography will be considered.

62. HALF-LIFE VALUE

a. The half-life value (HLV) of an isotope is important in determining its value as a source of gamma rays. As a radioisotope emits radia-

tion, it decays, and the radiation intensity diminishes with the passing of time. The time required for the intensity to be reduced to 1/2 its original value is called the half-life value of the isotope.

b. Radioactive decay is essentially random in character and is kinetically a first-order process; i. e., one in which the rate of decay depends only upon the number of decaying atoms present. Each decay process is thus governed by the expression:

$$\frac{-dn}{dt} = \lambda n$$

where n is the number of atoms of the species present, and λ is a decay constant characteristic of that species. Integration of this expression and evaluation of the time necessary for one-half of the atoms present initially to decompose (i. e., the half-life value) gives:

$$t_{\frac{1}{2}} = \frac{0.6932}{\lambda}$$

c. The activity of a radioactive source is measured by its disintegration ratio. The curie is the unit of measurement of source activity, and is defined as the quantity of any radioactive material that has a disintegration rate of 3.7×10^{10} disintegrations per unit time. Radiation is measured in roentgens per unit of time, and one method of measuring source strength is by specifying the radiation output in roentgens per hour at one meter.

d. Table IX gives the half lives of the isotopes commonly used in radiography.

Table IX. HALF LIVES OF COMMONLY USED RADIOISOTOPES

Source	Half-Life
(1) Radium	1600 years
(2) Cobalt 60	5.3 years
(3) Iridium 192	73 days
(4) Cesium 137	33 years
(5) Thulium 170	127 days

Section II. COMMERCIALLY AVAILABLE GAMMA RAY SOURCES

63. GENERAL

a. It was explained earlier that the focal spot of an X-ray is that area on the target which is bombarded by the electron stream originating from the filament. The effective focal spot is smaller than the actual focal spot because of the downward orientation of the X-ray beam due to the angular cut of the target material.

b. In isotope radiography, the focal spot of an isotope is the actual physical area. For example, an isotope may be a 1/8-inch cube or a rectangle 3/16 x 1/8. Most isotopes used for radiography are cubes where each side is equal. In cases where the length of an isotope is greater than the width, the smallest dimension or area should be parallel to the work being radiographed, if the resulting radiograph is to be sharply defined. The geometric principles of penumbra apply to radioisotopes as well as to X-rays.

64. RADIUM

a. Radium is a naturally occurring radioactive material and consequently was the first element used for gamma radiography. It has a half-life of approximately 1600 years and for practical purposes may be assumed to emit radiation at a constant rate. Actually, the radium itself does not emit gamma rays, but decomposes into a gas. This gas, called radon, also decomposes; as it decomposes, it emits gamma rays. Radon has a half-life of only 3.85 days. The amount of gamma rays given off is directly proportional to the quantity of radon. The radium itself is contained in a gas-tight capsule. This prevents the radon gas from escaping and establishes a state of dynamic equilibrium, with the rate of formation of radon just equal to the rate of decomposition of radon. It is this dynamic equilibrium that enables gamma rays to be given off at a constant rate.

b. Pure radium is not used in radiography. Radium sulphate is commonly used. The shape of the source depends on its size. Small sources are usually spherical in shape while the larger ones are cylindrical. It should be emphasized again that with a cylindrical source, it is important that the smallest surface of the capsule point at the object being radiographed. This surface represents the focal spot, and the smaller the focal spot, the greater is the definition obtained.

c. The cost of radium is extremely high, making its use limited, but it is possible to rent radium at a reasonable cost.

65. COBALT 60

a. The half-life of Cobalt 60 is relatively short when compared with radium. Its half-life of 5.3 years cannot be considered as a constant

source strength, at least from the radiographer's standpoint. The correction of the source strength factor at intervals of six months sh be sufficiently accurate. Table X shows the decay rate for intervals of six months up to its half-life value after 5.25 years.

Table X. COBALT 60 DECAY RATE

Life (Months)	Source Strength
6	0.9366
12	0.8772
18	0.8220
24	0.7695
30	0.7211
36	0.6757
42	0.6325
48	0.5927
54	0.5549
60	0.5200
63	0.5000

b. Cobalt 60 gamma rays give slightly less sensitivity than can be obtained with radium. By employing slow speed and fine grain films at densities greater than 2.0, a sensitivity of 2 percent can be obtaine Cobalt 60 is an excellent substitute for radium. Its advantages are low cost, high specific activity, and small source size. The disadvantages are that it does not result in as good a sensitivity as radium, and its decay is much more rapid, requiring frequent correction of the source strength figure and therefore longer exposure times.

c. To be at all practical, the radiographic gamma ray source shoul be equivalent to a minimum of 0.5 grams of radium. With a source of this size, approximately 15 hours of exposure time using a slow film would be required to radiograph one inch of steel.

d. With sources equivalent to 1.5 grams of radium and larger, a longer source-to-film distance can be utilized. This practice will result in better sensitivity, as well as shorter exposure time with the larger source. Sources of 1,000 curies of Cobalt 60 and larger are now available for heavy work.

e. Steel thickness less than 3/4 inch should not be radiographed with Cobalt 60. Better results will be obtained on larger thicknesses. Cobalt 60 emits gamma rays having energies of approximately 1.25 mev. The use of a 10-curie source cuts the time of exposure down to the levels shown in table XI. The figures shown are representative, using medium speed film and a 20-inch source-to-film distance.

Table XI. STEEL EXPOSURE CHART FOR COBALT 60, 10- CURIE SOURCE

Steel Thickness (Inches)	Exposure Time
1	24 seconds
2	3 minutes
3	13 minutes
4	44 minutes
5	4 hours
6	6 hours

66. IRIDIUM 192

The most promising isotope for radiography of thinner materials appears to be Iridium 192. This is due to its very high specific activity and its extremely small source size. A two-curie source of Iridium 192 which measures only 1 mm x 1 mm may be procured. This isotope is relatively inexpensive and easily obtainable. The disadvantage of its short half-life of 73 days does not appear to be too critical to prohibit its use. For a thickness range of 1/4 to 1-1/2 inches, the defect sensitivity is extremely good and far in advance of Cobalt 60 or Cesium 137. Iridium 192 produces soft rays comparable to those produced by X-ray tubes operating from 220 kv to 400 kv. Sensitivities of 2 percent have been easily obtained. It possesses high specific activity but relatively low energy.

67. CESIUM 137

a. The specific activity or intensity of Cesium 137 is lower than that obtained with Cobalt 60. This factor will of course tend to increase the source size and reduce the thickness levels of materials to be examined. Cesium 137 is most effective in the thickness range of 1 to 2-1/2 inches of steel. Fine grain films with large source-to-film distances are required to obtain the desired sensitivity.

b. Cesium 137 has a long half-life value of 33 years and produces results comparable to the one-million volt X-ray unit; however, it has no speed advantage over Iridium 192 and is actually slower than Cobalt 60. Iridium 192 has better sensitivity at thicknesses less than one inch, and it is believed that Cobalt 60 can do equally as well as Cesium 137 at thicknesses of from 1 to 3 inches. At thicknesses over 3 inches, Cobalt 60 is superior.

c. Cesium 137 has a gamma ray output of 0.39 roentgen per hour per curie at a distance of one meter from the source. An indication of its slowness is shown by the fact that in using a 20-inch source-to-film distance with a 0.5-inch thickness of steel, an exposure time of

approximately 0.8 hours would be required to obtain a density of 2.0 with a 225-millicurie source.

68. THULIUM 170

Thulium 170 is now available for radiographing very thin sections of materials which could not be radiographed with other radioisotopes. The present disadvantage of Thulium 170 is that it is extremely costly. Its half-life is said to be 127 days. It is comparable to X-ray machines in the vicinity of 85 to 100 kv, and its output is extremely low, yielding 25 milliroentgens per hour per curie at one meter. The source dimensions are reasonably small, with a one-curie source measuring one mm diameter. A 50-curie source measuring 3 mm x 3 mm will give 2 percent sensitivity on representative thicknesses shown in table XII. The figures in this table were derived using medium speed film, no screens, and a source-to-film distance of 12 inches.

Table XII. EXPOSURE CHART FOR THULIUM 170,50-CURIE SOURCE

Material	Thickness (Inches)	Exposure Time
Stainless Steel	0.050	36 Min.
	0.200	1.8 Hr.
Titanium	0.200	34 Min.
	0.400	2.1 Hr.
Aluminum	0.200	20 Min.
	0.750	47 Min.
	1.400	1.8 Hr.

69. COMPARISON OF ISOTOPES WITH X-RAY UNITS

On comparing isotopes with X-ray units, certain basic differences are noted:

a. The kilovoltage and therefore the radiation energy of X-ray machines are variable. This makes them more suitable for a variety of materials and objects and also allows the selection of an optimum value for each job. On the other hand, each isotope gives off only its characteristic radiation and cannot be adjusted or changed.

b. Although X-ray machines require supplementary electrical power, they can be turned off and on at will. An isotope, however, requires no supplementary power, thus making it more adaptable to field and shop work where lack of space would normally prevent the use of X-ray equipment. The fact that an isotope is always giving off

radiation makes it a safety hazard controlled only by strict conformance with safety regulations.

c. X-ray machines are capable of producing radiations that are more intense than those produced by isotopes, thus permitting shorter exposure times.

70. SHIELDING

a. Table XIII gives the amount of shielding required to reduce the radiation intensity of various isotopes to their approximate half-value layers, and values from which the entire amount of shielding required can be computed.

Table XIII. APPROXIMATE HALF-VALUE LAYERS FOR ISOTOPES (INCHES)

Material	Ir 192	Cs 137	Tm 170*	Co 60
Lead	0.08	0.39	0.05	0.47
Steel	0.52	0.67	0.32	0.75
Concrete	1.75	2.00	1.10	3.00
Water	4.00	5.00	2.50	7.00

*Estimated only

b. Table XIV gives the known emission or (dose) constants expressed as roentgens per curie at a distance of one foot from the source. This information may be of greater assistance to the radiographer than the information given in terms of meter distance. Here also, the inverse square law can be used to compute the dose rate at any desired distance.

$$\frac{I_o}{I_1} = \frac{(d_1)^2}{(d_o)^2}$$

where:

I_o = initial radiation intensity
I_1 = radiation intensity unknown and desired
d_1 = distance at which X intensity is desired
d_o = initial distance

Table XIV. EMISSION CONSTANTS

Element	Dose Rate*	Dose Rate**	Half-Life
Ir 192	5.9	0.55	73 days
Cs 137	4.2	0.39	33 years
Tm 170	0.0299	0.0025	127 days
Co 60	14.5	1.35	5.3 years

* r/hr/curie at one foot

** r/hr/curie at one meter

c. With a known dose rate for any radioisotope, the shielding necessary to reduce the radiation to safe levels can be readily computed. Typical problems are worked out below:

"Problem" No. 1

"What is the radiation intensity of two curies of Cobalt 60 at a distance of six meters from the source?"

Knowing that a one-curie source of Cobalt 60 will have an intensity of 1.35 roentgens, or an equivalent of 1350 milliroentgens per hour per curie (taken from table XIV) at a distance of one meter, proceed as follows:

X = desired intensity information at six meters

2700 = intensity of two curies at one meter,

then proportionately:

$$\frac{I_o}{I_1} = \frac{(d_1)^2}{(d_o)^2}$$

$$\frac{X}{2700} = \frac{1^2}{6^2}$$

$$36X = 2700$$

$$X = 75 \text{ mrem/hr (at 6 meters from source)}$$

"Problem" No. 2

"A two curie source of Cobalt 60 is to be used in the center of a room which is 12-meters square. How much concrete shielding is required to reduce the radiation intensity to a level of 2 mr/hr or less outside the wall?"

In the previous problem, it was shown that the intensity of radiation at six meters from a two-curie source of Cobalt 60 was approximately 75 milliroentgens per hour. From table XIII, the approximate half-value layer of concrete is three inches. Therefore, 18-inches of concrete is equivalent to six half-value layers.

$$1/2 \times 1/2 \times 1/2 \times 1/2 \times 1/2 \times 1/2 = (1/2)^6 = 1/64$$

Then the shielded dose rate would be: 75 mrem/hr divided by 64 equals approximately 1.17 mrem/hr with an 18-inch wall of concrete.

"Problem" No. 3

"Using Cobalt 60 with given dose rate of 14.5 r/hr/curie at one foot (taken from table XIV), determine the dose rate at a three-foot distance from the source."

$$\frac{I_o}{I_1} = \frac{(d_1)^2}{(d_o)^2}$$

$$\frac{14.5}{X} = \frac{3^2}{1^2}$$

$$\begin{aligned} 9X &= 14.5 \\ X &= 1.61 \text{ r/hr or} \\ \text{Dose rate} &= 1610 \text{ mrem/hr at 3 ft.} \end{aligned}$$

Section III EXPOSURE FACTORS

71. GENERAL

The exposure of the gamma ray source must take place in some inclosed or deserted area. It is ideal to have a concrete exposure room for gamma radiography. If this proves too costly, the exposure may be made in some deserted area, roped off to exclude personnel.

72. FACTORS AFFECTING EXPOSURE

a. The four factors that affect exposure are as follows:

(1) The intensity of the source.
(2) The source-to-film distance.
(3) Type of material being radiographed.
(4) Film and screens used.

b. Since the intensity of a source is fixed, there is little chance in varying the intensity. However, adjustments must be made to account for decreases in the radiation emitted as the source decays.

c. The source-to-film distance is a very important variable because of its flexibility. As the source loses its radiation, the source-to-film distance is decreased to offset the decay. The intensity varies inversely as the square of the distance from the source.

d. The type of material being radiographed will also affect the exposure. For thick, dense sections the time required for an exposure must be increased. If objects of different thicknesses are being radiographed at the same time, they must be placed at distances that will account for the variance in thickness.

CHAPTER 7

SPECIFICATIONS AND STANDARDS

Section I. GENERAL

73. GENERAL

a. The Department of Defense applies the principles of an established quality assurance program for procurement purposes. A procurement document will sometimes implement its quality assurance provisions by referencing a radiographic specification or standard. These documents may spell-out the radiographic procedure to be used in inspecting a material or item, or they may specify that personnel or equipment be qualified or certified, indicating applicable tests and examinations and providing for periodic certification reevaluation. The word qualification as used in this text means the determination and certification of capability, and is not intended to suggest qualification for a Qualified Products List.

b. Often, radiographic specifications or standards listed as applicable in a procurement document are mandatory under specified terms. If and when a contractor has demonstrated to the satisfaction of the procuring agency that a uniformly acceptable product is being delivered, the procuring activity may, at its own discretion, reduce the number of tests required. This can usually result in savings of both time and money.

74. SPECIFICATIONS

A specification is a document intended primarily for use in procurement which clearly and accurately describes the essential and technical requirements for items, materials, or services including the procedures by which it will be determined that the requirements have been met.

Specifications are prepared for items which vary greatly in complexity. They establish requirements in terms of complete design details or in terms of performance, but in most cases in terms of both design and performance.

75. STANDARDS

a. Standards are documents that establish engineering and technical limitations for items, materials, methods, designs, and engineering practices. They are created primarily to serve the need of designers, and to control variety. Standards represent the best solution for

recurring design and engineering and other logistic problems with respect to the items and services needed by the military services. Standards function in procurement through the medium of specifications.

b. The term radiographic standard is somewhat ambiguous. The documents called radiographic standards are not to be confused with the reference radiographs and standard samples of flaws which are also called radiographic standards.

Section II. RADIOGRAPHIC SPECIFICATIONS

76. GENERAL

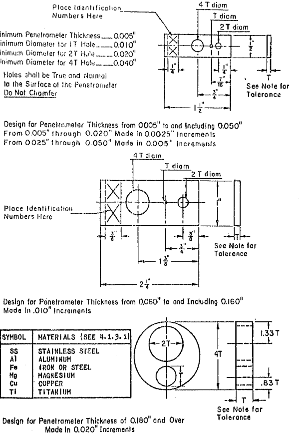
a. As stated previously, a specification is intended primarily for procurement purposes. It clearly and accurately describes the essential and technical requirements for items, materials, or services including the procedures by which the requirements are determined to have been met. Radiographic process specifications describe the radiographic tests deemed necessary for quality assurance.

b. Contractors supplying radiographic services to the Government, either directly or indirectly through subcontract, often find that the procurement order references a radiographic process specification. Under this specification, the contractor is required to fulfill certain basic functions and administrative details. For example, the sensitivity of the radiographic process is a function of both definition and contrast. These factors are indicated, and sensitivity is measured by a device called the penetrameter. The process specification will define the technical design and use of the penetrameter, and will establish the requirements for its display and interpretation (see par. 77). Administrative details concern the marking and identification of both the radiograph and the material being examined, and with the method and length of time that not only the radiograph itself but also other records must be kept and maintained.

77. PENETRAMETERS

a. The types and dimensions of the various penetrameters required for Department of the Army use are shown in figure 57. These penetrameters are as specified by MIL-STD-271 and by the American Society for Testing and Materials (ASTM). A penetrameter must be made of material which is radiographically similar to the object being radiographed. Penetrameters should be placed on the source side of the specimen and at maximum obliquity from the source.

b. The penetrameter thickness is always a percentage of the actual thickness of the object or that portion of the object being radiographed; it is not a percentage of the design or finish-machined thickness. The three holes in the penetrameter are referred to as 4T, T, and 2T dia-



NOTE.—Tolerances on penetrameter thickness and hole diameter shall be ±10 per cent or one half of the thickness increment between penetrameter sizes, whichever is smaller.

FIGURE 57. PENETRAMETERS

meter, respectively; or, in other terms, 8, 2, and 4 percent of the specimen thickness for which the penetrameter is designed. Unless otherwise specified, 2T radiography is normally required in all Department of the Army radiography. This means that the outline of the penetrameter and at least the 2T and 4T holes must be clearly visible on the radiograph.

78. RADIOGRAPHIC QUALIFICATION

a. Qualification, as applied to radiography, is the determination and certification of capability. A prospective vendor to the Government would normally perform certain tests and procedures to demonstrate his capabilities. At one time it was considered sufficient that the government merely reinspect a vendor's product to determine if his final inspection was adequate. Today, however, it is realized that nondestructive testing inspection methods, such as radiography, have broad application throughout the entire production cycle. To save time and money, therefore, it is necessary that the Government have proven confidence in the testing procedures and capabilities of the vendor so that the Government doesn't have to expend itself on inspecting whole lots of faulty products.

b. The many agencies of the Department of Defense each have radiographic qualification requirements. Since all of these requirements are based on the same quality assurance concepts, the same general end result is achieved. Common qualification requirements are set out in a test procedure which establishes:

(1) The physical adequacy of a facility for the range of radiography contemplated.

(2) The technical competence of the facilities' personnel to perform such work.

Radiographs of prescribed objects (test blocks, standard castings, etc.) are required to be made and interpreted in a satisfactory manner. The latitude available in a qualification or certification specification is sufficient to require that a facility be capable of maintaining a satisfactory level of quality workmanship under the production conditions contemplated. Provision is also made for periodic reexamination of the facility to assure continuance of quality work. All details of the test are performed by the facility attempting to qualify. Either surveillance of the test itself is maintained by a Government inspector, or only the final result is reviewed and judged by the Government agency involved

c. A detailed analysis of a radiographic qualification test is given in the Appendix.

79. RADIOGRAPHIC COVERAGE

a. General. Radiographic coverage, as used in specifications, is a term pertaining to the areas or sections of an item or component to be radiographically inspected. Certain areas of large items may be either very difficult or impossible to cover radiographically. Coverage of these areas and certain noncritical areas is not usually required by the item specifications. The term radiographic coverage should not be confused with terms such as percentage inspection, which refers to the percent of the items to be inspected rather than the areas to be radiographed on any one item.

b. Position Drawings. The usual means of specifying radiographic coverage is by radiographic position drawings. A position drawing is usually dimensionless and simplified, showing just enough detail of the part or structure to clearly indicate such required radiographic information as:

(1) The number and specific location of areas on each part required to be radiographed.

(2) Number and location of areas to be selected at random on each part to be radiographed.

(3) The acceptance reference standard for each area.

(4) The number of parts which are to be examined (i.e., percent or frequency of examination).

(5) Special instructions not otherwise provided for.

80. RADIOGRAPHIC TESTING SYMBOLS

a. General. The basic radiographic testing symbol consists of the two letters RT. The assembled testing symbol consists of the following elements:

Reference Line	Tail
Arrow	Extent of test
Basic Testing Symbol	Specification, process,
Test-all-around Symbol	or other reference.
(N) Number of Tests	

Only as many elements as necessary are used; the elements have standard locations with respect to each other as shown in figure 58. Radiographic testing symbols may also be combined with other nondestructive testing symbols and welding symbols.

b. Significance of the Arrow. The arrow connects the reference line to the part to be tested. The side of the part to be tested to which

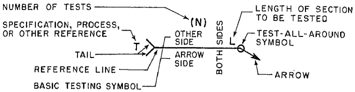


FIGURE 58. LOCATION OF ELEMENTS OF RADIOGRAPHIC TESTING SYMBOL

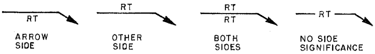


FIGURE 59. STANDARD LOCATIONS OF THE RADIOGRAPHIC TESTING SYMBOL

the arrow points is considered the arrow side of the part. The side opposite the arrow side of the part is considered the other side.

c. Location of Testing Symbol. Tests to be made on the arrow side of the part are indicated by the basic test symbol (RT) on the side of the reference line nearest the reader; tests to be made on the other side are indicated by RT on the side of the reference line away from the reader; tests to be made on both sides are indicated by RT on both sides of the reference line; and when test symbols have no side significance, they are centered on the reference line. Standard locations of the testing symbol are given in figure 59.

d. Direction of Radiation. When specified, the location of the source of radiation and the direction of radiation is shown in conjunction with the radiographic testing symbol. The location of the source of radiation is indicated by a symbol located on the drawing at the desired source or radiation, connected and oriented as necessary by dimensions, as shown in figure 60.

e. Specifying Extent of Radiographic Tests. Radiographic tests of areas are indicated by one of the following methods:

(1) For radiographic testing of an area represented as a plane on a drawing, the area to be tested is enclosed by straight broken lines with circles at each change of direction. When necessary, these enclosures are located by dimensions (fig. 61b).

(2) For radiographic testing areas of revolution, the area is indicated by using the test-all-around symbol (fig. 61a).

In general, most radiographs (with the exception of fillet welds) are taken with normal incidence between the X-ray beam and the surface of the area under test. However, provision is made in specification MIL-R-11471, Radiographic Inspection of Metals, for the use of other angles of incidence when necessary or more practical. In such cases, it is advisable that the direction of radiation be indicated by a sketch attached to the negative so that the person reading the films will have an understanding of the actual direction used.

Section III. RADIOGRAPHIC STANDARDS

81. GENERAL

The accuracy and reliability of any comparative test depends upon the use of functional and adequate standards and specifications. The information derived from a radiograph is of little consequence until compared to some reference. For example, if a radiograph of a casting indicates the presence of gas porosity, this fact is of no significance

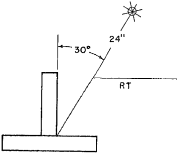
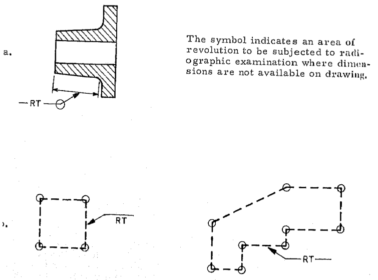


FIGURE 60. DIRECTION OF RADIATION



The symbol indicates an area of revolution to be subjected to radiographic examination where dimensions are not available on drawing.

FIGURE 61. SPECIFYING TESTS OF AREAS

unless the relative importance of such porosity is known. An engineering or service evaluation normally establishes a basis for such comparisons.

82. DESIGN OF STANDARDS

a. Procedure. Evaluations are conducted on items containing various flaws. The effect upon design constants and performance requirements are established, and standards of acceptability are chosen. Radiographs of both acceptable and unacceptable samples are then prepared and used as standards against which radiographs of production items are compared.

b. Choice and Use of Standards. Ideally, the design engineer chooses the standard of product quality, the radiographer uses this standard to judge product quality, and the production (or manufacturing) element is provided with an example of the quality level of product to be achieved.

c. Effective Standards. Sets of radiographs, showing various types and degrees of flaws and used as a guide in the evaluation of a material or item, are recognized as radiographic standards. The most effective standards reflect the better commercial practices. Standards should accurately portray those levels of quality actually encountered in production. Radiographs of extreme samples or conditions do not contribute to effective standards.

d. Supplementation of Radiographs. Radiographic standards are often supplemented by graphs and tables. For example, flaws such as slag inclusions or lack of penetration in welds are predictable both in their manner of occurrence and in their effect upon design requirements. Therefore, to cut down on the number of standard radiographs used, only one or two examples of such flaws are illustrated. The illustrations, however, are supplemented by tabular information on limits of flaw length versus thickness of material (and classes) as to limits for different levels of structural strength.

83. EXPERIENCE WITH STANDARDS

The continued use of radiographic standards normally results in the accumulation of considerable data relating to the service performance of the materials involved. A proper evaluation of such data often enables quality assurance engineering personnel to develop a category of defects and their limits of severity for various applications. Thus, defect limits for high, medium, and low stressed areas or parts may be put in tabular form. Often, it is necessary to consider both service requirements and the effects of failure of the component. This can also be done in tabular form and will assist design engineers in selecting quality levels for more rapid evaluation by inspection.

CHAPTER 8

SAFETY

Section I. GENERAL

1. GENERAL

a. Radiation can be extremely dangerous to the human body. Many of the early pioneers in radiology, ignorant of the physiological effects of radiation, became seriously ill, crippled, and some eventually died from the effects of over-exposure to radiation. These unfortunate experiences prompted extensive research on the subject. Today, sufficient knowledge is available on how the body is affected so that adequate protection rules and safeguards can be given. When these precautions are observed, radiography can be carried out with complete safety.

b. It should be emphasized that radiography is only as safe as the people working with it want it to be. The basic assumption of anyone working in the field should be that any unnecessary exposure to radiation, no matter how small, is too much.

2. RADIATION UNITS OF MEASUREMENT

a. At the present time there are three generally accepted units which relate to radiation exposure and absorbed dose. They are the roentgen, the rad, and the rem, and are defined as follows:

(1) The ROENTGEN (r) is a measure of radiation exposure based upon the amount of ionization produced in air by a radiation source. When the specific ionization is such that one electrostatic unit of electrical charge is produced per cc of air under standard conditions, then the exposure dose is one roentgen at the point at which the measurement is made. The roentgen output of a radiation source can be measured with relative ease by a properly constructed ionization chamber.

(2) The RAD is the unit of absorbed dose and by definition is the absorption of 100 ergs of energy per gram of irradiated material. The rad dose can be determined from ionization chamber measurements within the test object, by measurement of temperature change of the test object, or by chemical dosimeters.

(3) The REM (rad or roentgen equivalent man) is the absorbed

dose in rads multipled by the relative biological effectiveness (RBE) of the radiation used on the particular biological system irradiated. RBE may be defined as the ratio of doses from two different radiations that produce the same biological change. At the present time, there is no dosimeter that can directly measure the rem.

b. The currently accepted unit of radiation dose to biological systems is the rem. Its usefulness lies in the fact that the biological and physical properties of the test object are taken into account, as well as the ionizing characteristics of the radiation employed. Equal rem doses to the same biological test object delivered by, for example, neutrons and alpha particles should produce the same biological change. Any of the following may be considered as equivalent to a dose of one rem:

(1) A dose of 1 r due to X- or gamma radiation.

(2) A dose of 1 rad due to X- or gamma radiation.

(3) A dose of 0.1 rad due to neutrons or high energy protons.

(4) A dose of 0.05 rad due to particles heavier than protons and with sufficient energy to reach the lens of the eye.

86. MAXIMUM PERMISSIBLE DOSES

a. The currently accepted maximum permissible doses have been established upon consideration of the estimated exposure of early radiation workers and also upon the radiation that man has always received from such natural sources as radium, cosmic rays, and Carbon 14. Radiation workers who, it is estimated, received 0.1 r per day for periods of many years have not exhibited any harmful effects which can be directly attributed to radiation.

b. Title 10 Code of Federal Regulations, Part 20 (10CFR20) contains the Atomic Energy Commissions (AEC) regulations on Standards for Protection Against Radiation. This regulation establishes a maximum dose from radiation source in any period of one calendar quarter to an individual in a restricted area as follows:

(1) Whole body, head and trunk, active blood forming organs, lens of eyes, or gonads------------------	1 1/4 rems
(2) Hands and forearms, feet and ankles------	18 3/4 rems
(3) Skin of whole body-----------------------	7 1/2 rems

c. Under certain conditions, the AEC allows these values to be exceeded. For a complete treatment of this subject the reader should

consult with the latest issue of the publications listed in the bibliographies under SAFETY, published by the National Bureau of Standards, the National Committee of Radiation Protection, the Atomic Energy Commission, and the Department of the Army.

Section II. PROTECTION AGAINST X-RAYS

87. GENERAL

Personnel may become exposed to X-radiation coming either directly from the X-ray tube target or from some object in the direct path of the X-ray beam. Therefore, while an exposure is being made, the operator and all other personnel must be protected by adequate shielding from the X-ray tube itself, the part being radiographed, and any other item exposed to the X-ray beam.

88. PROTECTION

a. Protection can be provided in a number of ways, depending upon the X-ray installation and the use to which it is put. Whenever possible, protective measures should be built in as permanent features of the installation. Preferably, the X-ray generator and the work should be enclosed in a room or cabinet, with the necessary protection incorporated in the walls. The common method is to locate the X-ray tube within a room completely lined with lead of a sufficient thickness to provide adequate protection. All the X-ray machine controls are located outside the room.

b. In placing of equipment and design of protective enclosures, certain principles must be kept in mind. Careful application of these principles adds to the safety of the personnel, and may decrease cost. Both safety and economy will be promoted if the amount of radiation which must be absorbed in the outside wall of the enclosure is kept to a minimum. To this end, the distance from the X-ray tube target to any occupied space should be kept as great as possible. Further, if the nature of the work permits, the direct beam should never be pointed toward these occupied areas, and the angulation of the tube should be restricted to a minimum.

c. Ideally, the lead housing around the X-ray tube should give protection against all primary radiation except the useful beam, although this is not always feasible in practice. The useful beam i' should be limited in cross-section by the use of cones or diaphı

d. If there are parts of the X-ray room which, because of tl sign of the equipment, can never be exposed to direct radiation tain economies in the installation of protective material are pos Where only scattered radiation can reach a protective wall, les tection is necessary, since the intensity of the scattered radiati

much lower than that of the primary. When advantage is taken of these economies, great care must be exercised in rearranging equipment, lest it become possible to direct the full intensity of the X-ray beam against a wall providing protection against the scattered radiation only.

e. In some cases where large numbers of relatively small parts are inspected, the protection may be in a more compact form. This consists of a lead-lined hood surrounding the X-ray tube, the specimens, and the cassette, thereby completely enclosing them for the duration of the exposure. When the exposure is completed, the hood is opened to allow the removal of the radiographed parts and the placement of a new batch. The electrical controls are interlocked so that the X-rays cannot be turned on until the hood is closed.

f. The protective material (usually lead) in the walls of the enclosure, whether it be room or cabinet, should be of sufficient thickness to reduce the exposure in all occupied areas to as low a value as is possible or economically feasible.

g. In some cases it may be possible for the personnel of an X-ray department, or other employees, to be exposed to radiation from more than one X-ray machine. In such cases, the amount of protection must be increased to a point where the total exposure in any occupied area is within the prescribed limits.

h. If the object is too large or heavy to be brought to the X-ray machine, the radiography must be done in the shop. Under such conditions, special precautions are necessary. These include a completely lead-lined booth large enough to accommodate the X-ray machine controls, the operator, and other X-ray workers. The booth may be completely enclosed, or open on one side. In any event, the exposure within it should be very carefully measured. Lead cones on the X-ray machine should be used to confine the X-ray beam to a certain direction and to the minimum angle that can be used. Portable screens should be provided to protect workers nearby. Guard rails or ropes and warnings should be used to keep plant personnel at a safe distance.

i. In field radiography, protection is usually obtained by distance. Care should be taken to see that all personnel are far enough away from the radiation source to ensure safety.

Section III. MATERIALS AND CONSTRUCTION FOR PROTECTION AGAINST X-RAYS

89. GENERAL

Lead is the most common material used to provide protection against X-rays. It combines high protective efficiency with low cost and easy

availability. In most cases, recommendations on protective measures are given in terms of lead thickness.

90. CONSTRUCTION

a. When using lead for protection, care must be taken to avoid any leaks in the shielding. This means that adjacent lead sheets should be overlapped, not merely butted, even if the sheets are to be burned together throughout the whole length of the joint. The heads of any nails or screws which pass through the lead should be carefully covered with lead.

b. Extra precautions should be taken at those points where water pipes, electrical conduits, or ventilating ducts pass through the walls of the X-ray room. For small conduits and pipes, it is usually sufficient to provide a lead sheathing around the pipe for some distance on one side of the lead protective barrier in the wall. This sheath should be continuous and very carefully joined, by a burned joint, to the lead in the wall. Better protection is afforded by having a right-angled bend in the pipe either inside or outside the X-ray room. The pipe is then covered with a lead sheath to a point well beyond the right-angle bend. The sheath should be carefully joined to the lead in the wall. In the case of a large opening for ventilation, lead baffles arranged as in figure 62 will stop X-rays, while permitting the passage of air. When a large ventilating duct is brought into the X-ray room, two right-angled bends covered with lead will prevent the escape of X-rays.

c. To test the protection, it may be necessary to put up X-ray films against the outside of the wall in questionable areas, and to direct the full intensity of the X-ray beam against each of these areas in turn.

d. If the X-ray room is on the lowest floor of a building, the floor of the room need not be completely protected. However, the lead protection in the walls should not stop at the floor level. An "apron" of lead, continuous with the protection within the wall, should be placed in the floor, extending inward from all four walls (fig. 62). The purpose of this apron is to prevent X-rays from escaping from the room by penetrating the floor and then scattering upward outside the protective barrier. An alternative is to extend the lead protection in the walls downward for some distance below the floor level. The same considerations apply to the ceiling if the X-ray room is located on the top floor of a building. Of course, if there is occupied space above or below the X-ray room, the ceiling or floor of the X-ray room must have full radiation protection over its whole area.

91. OTHER MATERIALS

Although lead is the most efficient material for X-ray protection, other materials find some application. In particular, structural walls

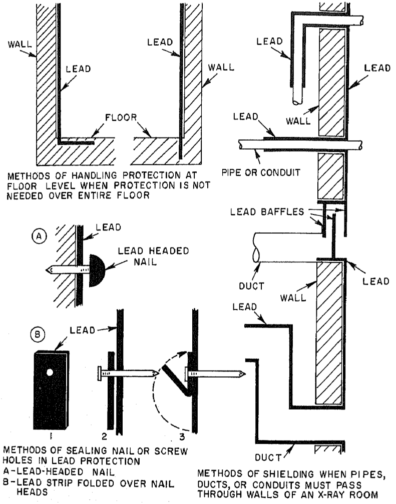


FIGURE 62. CONSTRUCTION FOR PROTECTION FROM RADIATION

of concrete or brick may afford considerable protection and may reduce the thickness, and therefore the cost, of the lead required. It is at voltages above 400 kv that concrete is most used as a protective material. The lead thicknesses required at these potentials are so great that fastening them to the walls becomes a serious problem, and concrete is used because of the ease of construction.

Section IV. PROTECTION AGAINST GAMMA RAYS

92. GENERAL

a. The gamma rays from radioactive materials have biological effects similar to those produced by X-rays. It is necessary, therefore, that the personnel conducting gamma ray work be informed of the safety precautions used.

b. Gamma rays may be very penetrating. For instance, 1/2-inch of lead reduces the intensity of the gamma rays of radium or Cobalt 60 only about 50 percent. This makes the problems of protection somewhat different from those encountered in protection against moderate-voltage X-rays. In general, it is not feasible to provide safety from gamma rays solely by means of a protective barrier. Therefore, distance or a combination of distance and protective material is usually required. When radioactive materials are not in use, protection may be obtained by keeping them in thick lead containers, since in this case the total amount of lead needed is not great. If it is not desirable to use the amount of lead required for full protection, the thick lead container may itself be kept in a wooden box of such dimensions that the gamma ray intensity at the outer surface of the box is reduced by a distance of a satisfactorily safe level.

93. STORAGE

In cases where the radioactive material is used in only one place in the plant, it may be stored in a narrow well in the earth at least 6 feet deep directly beneath the spot it occupies during an exposure. The gamma ray emitter remains in the well when not in use, and while specimens and film holders are being put in place or removed. However, the well must be closed with an efficient plug in order to ensure the safety of the region near it. When an exposure is to be started, the source is raised to the desired position by a simple mechanism operated from a safe distance.

94. TRANSPORTING GAMMA RAY SOURCES

a. If it is necessary to transport gamma ray emitters about the plant, a thick-walled lead box should be provided. The lead thickness should be at least equal to that of the appropriate shipping container, and the box should have a rigid handle which will keep the radioactive

material a safe distance from the body. The length of handle required will depend, of course, upon the lead thickness and the strength of the source. The carrying case should be so constructed that it is impossible, or at least inconvenient, to pick it up or pull it other than by the handle.

b. In transferring a gamma ray emitter to or from the storage container, truck or exposure position, it should never be handled directly, but by strings or tongs. If the container housing the radioactive material is magnetic, it may be handled by means of a small electromagnet, powered by dry cells, on the end of a long rod. In any event, such transfers should be done quickly and efficiently, and by trained operators. Special precautions should be taken to prevent loss of or damage to the radiation source.

95. SHIELDING WHEN USING GAMMA RAY SOURCES

a. Because of the great thicknesses of protective materials required for shielding some gamma ray sources, the most economical method of protection, while the source is in use, is by distance. A danger zone should be roped off around the location of the radioactive material, and personnel should be forbidden to enter this zone except to put the source in position or return it to its safe. Suitable conspicuous signs should be provided to warn off the casual passers-by. Tables and charts should be provided which give data for calculating the distances from various amounts of radioactive material at which a radiation hazard exists.

b. It must be kept in mind that the presence of a large mass of scattering material, e.g., a wall, may materially increase the gamma ray dose. This increase may be as much as 50 percent of the dose as calculated without the presence of scattering material. Thus, to ensure that the radiation protection is adequate, factors other than distance must be kept in mind when considering personnel protection from gamma rays.

96. SHIPPING PRECAUTIONS

a. Precautions must be taken in shipping radioactive materials not only to protect those who will handle them in transit, but also to prevent the fogging of photographic materials which may be transported in the same vehicle. The Interstate Commerce Commission has set up regulations governing the rail shipments of radioactive isotopes. Packages meeting these requirements often consist of a central lead container surrounded by a wooden or other box of such dimensions that the radiation assessible at the surface is less than 200 mr per hour. It is highly advisable to preserve the original shipping container in case it is again necessary to ship the source.

b. A danger, rarer but graver than exposure to the emitted gamma radiation, is the inhalation or ingestion of radioactive material. With

radium, there is the possibility of inhalation of radon gas by the personnel. Radon is a radioactive product of radium disintegration. The radium is sealed in a gas tight container by the supplier, to prevent radon leakage. As a result of mishandling, however, the container may spring a leak and allow the radon to escape to the atmosphere where it may be inhaled. It is suggested that all radium capsules be tested for leakage, and that thereafter any capsule that has received physical damage be again tested. A sudden drop in the gamma ray emission of a radium capsule is suggestive of radon leakage, and under such circumstances the capsule should be tested immediately.

97. DAMAGE TO GAMMA RAY SOURCES

In general, it may be said that any physical damage to a gamma ray source should be suspected of having allowed leakage of radioactive material. This is particularly the case if the gamma ray emitter has a gaseous disintegration product, as does radium, or is in the form of a powder, as are radium, Cesium 137, and some Thulium 170 sources. The capsule itself and the plant area in which the damage occurred should be surveyed by safety personnel; all other personnel should be excluded until the possibility of escape of radioactive material has been eliminated.

Section V. RADIATION DETECTORS

98. GENERAL

There are four principal types of radiation detectors which have found wide application to the problem of personnel protection. These are the "Ionization Chamber Type (Cutie Pie)," the "Portable Geiger Counter," the "Pocket Dosimeter," and the "Film Badge."

99. TH IONIZATION CHAMBER TYPE SURVEY METER (Cutie Pie)

a. This is a ratemeter device which instantly r radiation levels and, if equipped with a suitable for beta ray monitoring (fig. 63). Because th available instruments will indicate dose rates as low as 2 milliroentgen per hour, this device has found wide application to radiation surveys of X-ray installations and radium and radioisotope storage areas. Mos available instruments have three sensitivity ranges of 0-25, 0-250, and 0-2500 milliroentgens per hour. If precise results are required, the instrument should be calibrated at the energy range of interest.

b. The advantage of a cutie pie is that radiation levels are measure within a few seconds. It also has relatively high sensitivity and flatness of response with change of X-ray energy. The disadvantages are

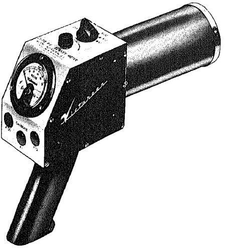


FIGURE 63. "CUTIE PIE" SURVEY METER

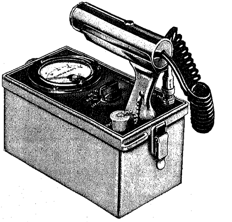


FIGURE 64. PORTABLE GEIGER COUNTER

its relatively large size and delicate construction, and warmup drift during the first few minutes of operation. A readily available and easy-to-use reference standard is an extremely important accessory for this type of device.

100. THE PORTABLE GEIGER COUNTER

a. This is a ratemeter device which may supplement the cutie pie but in no way replace it as a radiation survey instrument (fig. 64). Although most portable geiger counters have dials calibrated in milliroentgens per hour as well as in counts per minute, the basic differences in operation between geiger tubes and ionization chambers limits the use of the milliroentgen scale to that X-ray quality at which the device was calibrated. An instrument whose miliroentgen scale was calibrated against radium may be in error by a factor of 4 when 100 Kv X-rays are monitored.

b. The advantages of the portable geiger counter are mainly its high sensitivity and rugged, trouble-free operation. On the most sensitive range, available instruments will detect radiation levels of 0.1 milliroentgen per hour.

c. As a radiation survey instrument, its main disadvantage is its non-linear response (milliroentgens per hour) with change in X-ray energy.

d. One of the most useful applications of the portable geiger counter is the rapid monitoring of radioisotope laboratories for contamination and the location of "lost" radioactive sources.

101. THE POCKET DOSIMETER

a. This is an integrating type ionization chamber whose most sensitive range is usually from 0 to 200 milliroentgens (fig. 65). Many of these instruments have built-in electrometer circuits so that the accumulated dose may be noted at any time. The only accessory equipment needed is a charging unit.

b. The main advantages of the pocket dosimeter are its small size, high sensitivity, instantaneous reading of accumulated dose, and relatively flat response to radiations of different energies. The greatest problem which arises in the routine use of this device is the electrical leakage which tends to discharge the electrometer and give false high readings. For precise work, leakage tests should be performed on each chamber before and after application.

c. Pocket dosimeters have found wide application in monitoring personnel during procedures which last but a few hours and where knowledge of the radiation exposure for that particular procedure is needed.

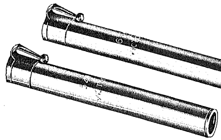


FIGURE 65. POCKET DOSIMETER

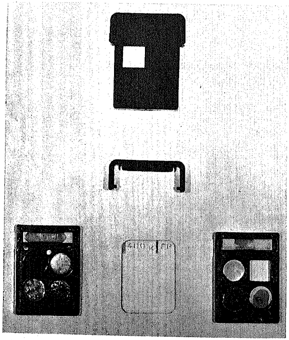


FIGURE 66. FILM BADGE

102. THE FILM BADGE

The most widely used personnel monitor is the film badge (fig. 66). It is used principally to record the dose accumulated at a low rate over a long period of time. It has the advantage of being extremely rugged, capable of fairly accurate interpretation over the range of X-ray qualities used in radiography, and a very long time period over which a single film may be used. Its disadvantages are that the wearer is never aware of the accumulated dose until the film is developed, and at the time he receives the film badge report he may not be able to recall any incident responsible for an over-exposure.

Section VI. ELECTRICAL SAFEGUARDS

103. GENERAL SAFEGUARDS

Radiographic inspection with X-rays presents a twofold safety problem to personnel. First, as previously mentioned, X-rays have a very destructive effect on the human body. Second, the extremely high voltages can deliver an electrical shock that may be fatal.

104. ELECTRICAL HAZARDS

a. Fortunately, most modern radiographic equipment is truly shock-proof when properly assembled, and most permanent installations offer little danger when personnel are trained in safe practice. Portable equipment, however, can pose serious safety problems if operating and inspection personnel do not employ certain necessary precautions.

b. In X-ray circuits, flexible cables must be used between the power source and the tube so that the X-ray head can be positioned to radiograph objects of all shapes and sizes. Flexible cables are also used between the X-ray tube unit and the control panel. Because extremely high voltages are used, these cables are covered with a heavy layer of rubber or some other insulating material that provide protection against shock. However, old or damaged cables o insulation constitutes a grave danger of fatal shock. Cable moved only when the power is off, or special equipment such as rubber gloves, high voltage sticks, and rubber n

105. PRECAUTIONS

The following electrical safety precautions should always be observed wherever X-ray equipment is operated or serviced:

a. The current should be off during the set-up procedure.

b. Cables should not be handled when power is on, and insulation should be frequently checked for wear.

c. Condensers must be discharged completely before a circuit is serviced or checked.

d. Proper safety equipment must be employed when "hot" cables are moved.

e. Persons who operate or work near X-ray equipment should learn artificial respiration and practice it enough to maintain proficiency. Prompt action immediately after an accident may save a life.

APPENDIX

RADIOGRAPHIC QUALIFICATION TEST

CONTENTS

INTRODUCTION

An analysis of radiographic qualification data generated over the past several years, supported with opinions of inspection personnel expressed during their attendance of the Nondestructive Testing Training Program held at Watertown Arsenal, indicates the following:

1. Lack of a clear understanding of qualification concepts by contractors.

2. Lack of understanding of the mechanics of qualification by some Procurement District personnel.

Therefore, it is the purpose of this report to review qualification procedures and to set forth the general concepts of qualifications as applied to the Army Materiel Commands (AMC) Quality Assurance System outlined in AMCR 700-6.

CONCEPTS OF QUALIFICATION

To comprehend the total effect of qualification upon the reliability of Army material, it is necessary to view it in its proper perspective. To accomplish this, let us first consider an important aspect of reliability; Quality Assurance. This may best be explained by reference to Section 3, paragraph a of the above cited AMCR, "Quality assurance." Quality assurance comprises a planned and systematic pattern of all actions necessary to provide adequate confidence that the product will perform satisfactorily in Service (MIL-STD 109)." It can be seen that quality assurance encompasses the elements of establishing quality standards, evaluating inspection and quality control systems, verification, reporting and inspection, in order to determine conformance of the product to specified requirements. It provides for follow up corrective action, whenever indicated, in order to improve the quality and reliability of AMC material.

From the above paragraph it is obvious that the radiographic qualification test supports this concept in that it is a quality assurance measure designed to assess contractor capability, thereby providing a medium of confidence in both the inspection system and the products accepted by this system. The qualification test established in Specification MIL-R-11470 is technically designed to ascertain the adequacy of equipment, facilities and personnel.

The contractor in attempting qualification is required to prove that his radiographic capability is adequate to perform in accordance with prescribed standards of workmanship. This does not mean that the vendor's honesty is being questioned. A conscientious vendor incapable of quality performance may be placed on the same level as a capable vendor without the best intentions. The prime interest then is one of assessing capability. The responsibility for evaluating this capability rests with the cognizant Procurement District.

A contingent benefit of requiring qualification is the psychological effect upon personnel. Contractors exercise more caution in performing even routine operations when they realize that the work performed is effectively subject to audit.

A latent benefit derived from qualification is the foundation of technical facts developed for use in surveillance. Surveillance is a powerful facet of quality assurance. It is in the area of surveillance where the cognizant Procurement District exercises its greatest influence. The radiographic qualification of a given facility represents only an initial step in total quality assurance. The prime consideration is the maintenance of consistently reliable inspection results throughout any given contract. Some district personnel do not fully realize nor utilize their authority to follow-up and insist upon quality radiography.

MECHANICS OF THE QUALIFICATION TEST

Preparatory Functions

The cognizant Procurement District upon determining the necessity for qualification by a vendor or contractor, can obtain the required test equipment kit (test block) by direct request to the U.S. Army Materiels Research Agency (AMRA). The preferred method of requisition is by means of submitting DD Form 1149-4, Requisition and Invoice/Shipping Document. The radiographic test kit will be sent directly to the Procurement District inspector at the point of use if so requested.

The radiographic test kit (Figure 1) consist of the following items:

1. One wooden shipping container
2. One wooden spacer
3. One lead shield (two sections)
4. One cracked plate C (3" x 6" x 1/8")
5. One plate D (3" x 6" x 1/8")
6. One plate E (3" x 6" x 1/4")
7. One plate F (3" x 6" x 1/2")
8. One plate G (3" x 6" x 1/2")
9. One plate H (3" x 6" x 1/2")
10. One plate I (3" x 6" x 1/2")
11. One plate J (3" x 6" x 1/4")

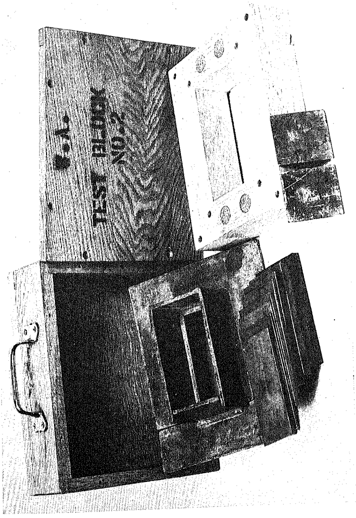


FIGURE 1. RADIOGRAPHIC QUALIFICATION TEST KIT

12. One plate K (5 1/2" x 2 1/2" x 1/4")

13. Two lead supports

During the waiting period between requisition and receipt of the test kit, the inspector should arrange a meeting with the contractors person charged with qualification. This meeting should suffice to acquaint the contractor with the desires of the Government through a review and explanation of Specifications MIL-R-11470 and MIL-R-11471.

Prior to the actual administration of the qualification test, the inspector should perform a survey of facilities which should include the following:

a. Source of Radiation - Information regarding the source, manufacturer's serial number of unit, serial and model number of tube, etc. should be recorded by the inspector on supplemental data sheets (see Figure 2) for submission with the radiographic test negatives upon conclusion of the test. The importance of serial numbers, etc., should no be taken lightly since they represent the only identification of a given radiation source.

The inspector should emphasize the fact that any change in the major components of an X-ray source will necessitate requalification. For example, the replacement of an X-ray tube creates the need for total requalification* in the same sense as the purchase of an entirely new machine, since the tube is the prime source of the radiation and is a critical item being evaluated. The source actually is defined as the X-ray tube and any associated components which influence the characteristics thereof. The transformer, focus coil power supply, tube housing, etc. are capable of influencing quality and are classified, therefore, as major components. When doubt arises as to the necessity of requalification, an inquiry to AMRA will resolve the matter quickly.

b. Processing Facilities - One of the most important phases of the radiographic cycle is film processing. It is at this point where a radiographic technique is summarized and also where a capable radiographer's efforts to produce an acceptable film may be frustrated through poor darkroom facilities, techniques or management. The pitfalls and variables associated with film processing are many. However, the following check points will provide the inspector with a good basis for assessing darkroom capability and are listed as follows:

1. Processing Tanks - Darkroom processing tanks are generally available in capacities starting at 5 gallons and increasing in capacity in increments of 5 gallons. The size of the tank should be adequate for handling anticipated production schedules so that films will not be crowded and subjected to scratching, scarring or poor processing due

ation will be discussed in more detail later

SPECIFICATION MIL-R-11470

RADIOGRAPHIC INSPECTION: QUALIFICATION OF EQUIPMENT, OPERATORS AND PROCEDURES

SUPPLEMENTAL DATA SHEET

NATURAL AND INDUCED RADIOACTIVE SOURCES

Facility ______

Location ______ Type of Isotope ______

A. E. C. License No. ______ Source of Manufacture ______

A. E. C. Authorized Person to Handle Source ______

Strength of Source ______ Date Strength of Source Determined ______

Physical Size of Source: Length ______ Diameter ______

Selected Optimum D/T Ratio ______

Material ______ Maximum Thickness ______

GOVERNMENT REPRESENTATIVES STATEMENT

In your opinion, do you believe that the above named facility is adequately equipped and staffed to perform industrial radiography according to Specification MIL-R-11471?

Yes ______ No ______

Date ______

______
Signature

______
Title

______
Procurement District

Remarks
______
______
______
______
______
______

FIGURE 2. PART A

SUPPLEMENTAL DATA SHEET

OPERATOR ______________________________

TEST DATA

IDENTIFICATION	1A	1BI	1BI	IB3	2A
EXPOSURE TIME					
SOURCE TO PART DIST. (D)					
PART TO FILM DIST. (T)					
D/T RATIO					
PENETRAMETER					
*MAXIMUM DIAMETER OF CAPSULE					
TYPE OF SCREEN					
SCREEN THICKNESS AT FILM: SOURCE SIDE					
OTHER SIDE					
BRAND NAME OF DEVELOPER					
DEVELOPING TIME					
DEVELOPING TEMP.					
BRAND NAME OF FIXER					
FIXING TIME					
WASHING TIME					
BRAND NAME AND TYPE FILM					
NEGATIVE DENSITY					

*Since capsule diameter is not always equal to capsule length, it is required that the largest dimension be given.

FIGURE 2, PART B

SPECIFICATION MIL-R-11470
RADIOGRAPHIC INSPECTION: QUALIFICATION OF
EQUIPMENT, OPERATORS AND PROCEDURES
SUPPLEMENTAL DATA SHEET
X-RAY EQUIPMENT

Facility ____________________

Location ____________ Machine Make ____________

Model ____________ Serial No. ____________ Type ____________

Tube Type ____________ Serial No. ____________ Test Block No. ____________

Has radiation survey been performed to determine freedom from health hazards? Yes ______ No ______

By whom was survey performed? ____________________

Date of last survey ____________________

Selected Optimum D/T Ratio ____________________

Material ____________ Maximum Thickness ____________

GOVERNMENT REPRESENTATIVES STATEMENT

In your opinion, do you believe that the above named facility is adequately equipped and staffed to perform industrial radiography according to Specification MIL-R-11471?

Yes ______ No ______

Date ____________________ ____________________
Signature

____
Title

____
Procurement District

Remarks

____

____

____

FIGURE 2. PART C

SUPPLEMENTAL DATA SHEET

OPERATOR ______________________________

TEST DATA

IDENTIFICATION	2A	2B1	2B2	2B3	2B4	2B5	3A
POTENTIAL (KV.)							
CURRENT (MA.)							
EXPOSURE TIME							
TUBE TO PART DIST. (D)							
PART TO FILM DIST. (T)							
D/T RATIO							
PENETRAMETER							
SCREEN MATERIAL							
SCREEN THICKNESS AT FILM: SOURCE SIDE							
OTHER SIDE							
DEVELOPER (BRAND)							
DEVELOPING TIME							
DEVELOPING TEMP							
FIXER (BRAND)							
FIXING TIME							
WASHING TIME							
TYPE FILM (BRAND)							
NEGATIVE DENSITY							

FIGURE 2. PART D

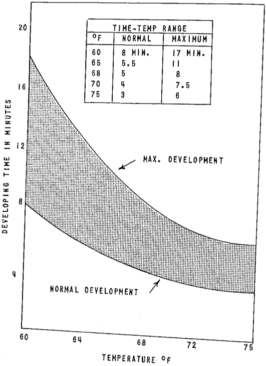


FIGURE 3. TIME - TEMPERATURE COMPENSATION CURVE

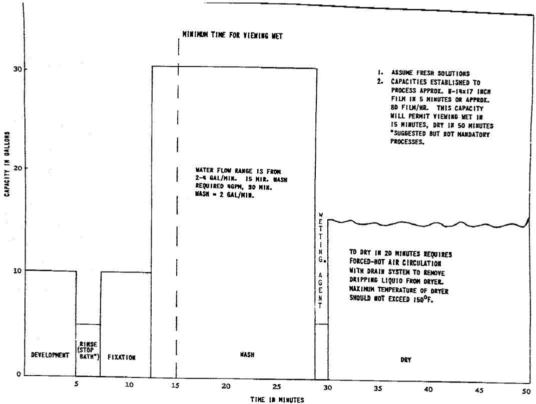


FIGURE 4. DARKROOM PROCESS CAPACITY CHART

8. Film and Solution Storage - Radiographic films must be stored in areas free from radiation and abnormal temperature. Solutions must be stored in areas not exceeding the temperature differential suggested by the manufacturer.

Together with the above items, particular attention should be given and subsequently reported concerning darkroom cleanliness and degree of orderliness. The inspector is reminded that evidence of poor darkroom practice has been the cause of many qualification rejections.

c. Film Interpretation Facilities - Every facility seeking qualification should provide a suitable area or room and equipment for viewing radiographs. The area must be equipped with viewing equipment with ample bench or table space to facilitate ease of viewing and recording of inspection results. Radiograph storage files should be provided for adequately storing radiographs which may be referred to subsequently.

d. Radiographic Facility Administration - The inspector should note whether a standardization system exists whereby radiographic techniques, identification, etc., are consistent throughout the duration of a government contract. Incorporated in this system, should be a method of identifying components which have been inspected.

e. Safety Requirements - Each facility desiring qualification should produce documented, authoritative evidence certifying that the radiation producing facilities have been surveyed and found to be free from stray radiation which could affect the health of government personnel. In this way the inspector will feel confident that adequate safety precautions have been taken. The safety of government personnel in a contractor's facility is discussed in detail on page 167.

The above listed five points must be examined in order to successfully assess or evaluate one phase of the contractor's physical ability to produce acceptable production radiographs.

Upon receipt of the test kit, the inspector can then proceed to arrange test details such as time and place of test and any other requirements deemed necessary.

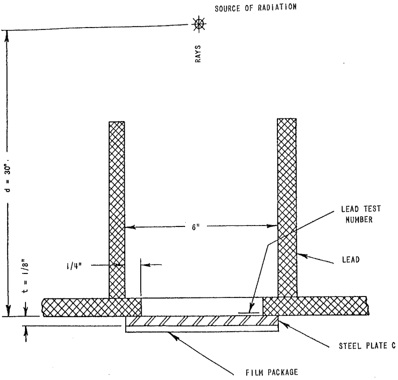
Operative Test

related to the process can cause a doubt to arise as to the capability of a contractor to maintain the required radiographic quality under production conditions. Request for qualification should be refused unless the physical facilities are adequate.

It is appropriate at this point to define the term "operator" as cited in paragraph 3.1.3 of Specification MIL-R-11470. The "operator" is defined as any person whose duties entail responsibilities for making decisions which could influence the quality of the radiograph. A technician operating under specific instructions without freedom to exercise independent judgment is not capable under this definition of influencing quality and need not qualify. However, a technician who selects his exposure factors is exercising independent judgment and must qualify. Darkroom technicians because they are bound by established technical routine are not required to qualify. The immediate (first line) supervisor of a radiographic installation is required to qualify. It has been the usual practice of contractors to seek qualification for several persons engaged in the conduct of the radiographic operation. A new employee will be required to qualify at such time as his duties within the radiographic unit justify qualification by virtue of the aforementioned definition. Determination of the need to qualify generally rests with the contractor; however, it is the prerogative and duty of the inspector to be cognizant of such conditions and to require qualification when the need is obvious.

b. Equipment Qualification - Theoretically, radiation produced by any X-ray machine will penetrate any thickness of material and, if given sufficient exposure time a radiograph could be obtained. Production radiographic inspection, however, could not afford the extensive times which might be required. The thickness of a material which an X-ray machine is capable of radiographing is based primarily upon the economics of inspection. Table I establishes what is regarded as minimum voltages by which radiography can be performed in a reasonable time for a given thickness of steel. This table must be followed. Cases have arisen where contractors have attempted to radiograph thicknesses in excess of the reasonable capacity of their equipment. The point to remenber here is that exposure times must be commensurate with good radiographic practice as employed in production radiography. Unrealistic exposure time is avoided in production work and should be discouraged for qualification purposes.

1. X-Ray Equipment Rated at 440 KVP or Less - Qualification of lower energy equipment is accomplished to establish the optimum working distance for a machine. This distance is determined as a function of what is termed the ratio of d/t which is illustrated in Figure 5. This ratio of d/t is based upon physical principles involving the geometry of projection. The sharpness (definition) quality of a radiograph is related directly to the working distance. The d/t determination of each radiation source is a most important point in the qualification effort. The minimum value of d/t establishes the working distance to be used in the operator qualification portion of the test and also fixes the distance to



SECTIONAL VIEW

FIGURE 5. EXPOSURE 2A SET UP

be used in subsequent production work. The optimum d/t ratio must be selected from those appearing in Table II. By imposing a minimum d/t value each source qualified will be operated at an optimum working distance thereby contributing to radiographic definition. The use of larger ratios will not degrade radiographic definition and is permitted in production.

2. Comparison Radiograph - The first exposure required is called the comparison radiograph and is identified as 2A (Figure 5). This radiograph is made using a 30-inch distance as specified with a 1/8-inch cracked plate as the object being radiographed. Hereafter, the cracked plate will be called plate C. The purpose of this initial radiograph is to serve as a standard in comparing subsequent radiographs made during the qualification test. Note that this radiograph has a d/t ratio of 240 and represents excellent definition. Any additional increase in distance will not improve greatly or contribute significantly to better image definition. Assuming that the correct radiographic technique has been used exposure 2A should depict the best detail obtainable with the machine. It should also be noted that the 30-inch distance only has been specified with all other exposure factors such as film type, screens, processing, etc., being left to the operators' discretion. In fact, this type of reasoning is followed throughout the qualification test. It should also be remembered that a penetrameter is not required for exposure 2A. The density of radiograph 2A and all other radiographs produced for qualification should be held constant to facilitate evaluation. A minimum density of 1.25 must be obtained. The only source filtration which is permitted for qualification test purposes is that inherent in the equipment. No additional filtration between the source and the subject (test block) can be permitted because it will present an effect which is not due to a true component part of the equipment and which could be removed or altered after qualification.

3. Test Series (2B1 through 2B5) - The determination of the optimum value of d/t is accomplished by making a series of 5 radiographs using the values and identification as outlined in Table II and set up in accordance with Figure 6. Although Table II specifies a 3-inch "thickness" between the film and the cracked plate C, it should be remembered that no buildup plates are used and there is effectively a void created by the 1/8-inch plate C resting on lead supports in the lead shield. Beginning with the first exposure, 2B1, of the test series, the focal distance is progressively increased to 60 inches for exposure 2B5.

> "There should be a progressive improvement in image detail as the value of d/t is increased until a value of d/t is reached where further increase ceases to cause a detectable improvement in image detail. For this value, the image detail should be essentially as good as that obtained in the comparison negative. The minimum value of d/t that gives image detail essentially as good as that obtained in the comparison negative is to be considered the optimum value to be used in subsequent work with the test block and in production work."

The phrase "essentially as good" may be construed as meaning the best compromise between sharpness and working distance. Because the working distance is increased as the d/t ratio becomes greater for a given material thickness and because increased working distance will result in additional exposure time and is therefore an economic factor, the lowest ratio of d/t which is commensurate with reasonably good definition is selected. The range of the test and the degree of ratio change between steps have been chosen to facilitate the best compromise selection. Radiograph 2A will always be superior to the 2B test series. Radiograph 2B5 will always represent the best quality of the test series. What is being sought is whether or not the difference in quality between radiograph 2B5 and those of lesser ratio is of sufficient significance to justify increased exposure time in production.

The educational benefit of this test is intentional and is an important factor of the qualification program.

4. <u>X-Ray Equipment Rated at 1000 KVP</u> - According to the Specification MIL-R-11470, X-ray machines rated at 1000 KVP can be used for radiographing thicknesses of steel up to 7 inches.

Determination of the working or focal distance for 1000 KV equipment using the procedure previously described for lower energy machines is, for reasons beyond the scope of this discussion, technically unsound and therefore is not required. The Specification states that, "the working distance shall be not less than 60 inches for radiographing through metal sections up to 3 inches and as much more than 60 inches as is practicable when radiographing through sections greater than 3 inches." It is realized that the imposition of a 60-inch distance can present difficulty in some cases. Due to changing radiographic technology it has been found that this distance may be shortened, without appreciably affecting the radiographic quality. However, a 60-inch minimum distance must be maintained in 1000 KV radiography until amendment to the contrary is promulgated. A waiver may be requested by the contractor and anted by the cognizant Procurement District in instances where hardp exists due to the specified 60-inch distance. The contractor should red to demonstrate that his intended procedure will produce

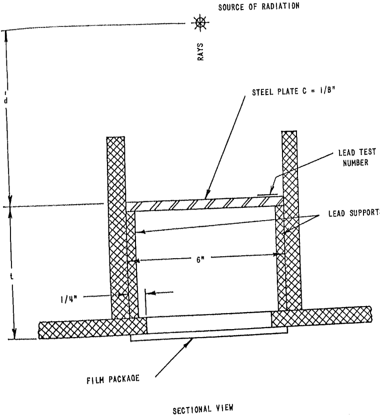


FIGURE 6. TEST SERIES (2B1 - 2B5) SET UP

The focusing coil current applies to a particular type of X-ray machine which was the only 1000 KVP type of equipment available at the time of specification preparation. It is stated in paragraph 3.2.3 of MIL-R-11470 that, "the current through the focusing coil shall be set at the values indicated by the manufacturer for the specific tube used." Since the focusing coil current affects the size of the focal spot, the inspector should be familiar with the recommended values for surveillance purposes.

5. Gamma Ray Equipment - Gamma radiography includes natural or induced radioactive isotope sources. It is necessary to determine the working distance for each source of gamma rays. A comparison negative is required and is identified as 1A. This exposure is made by placing the source of gamma rays 30 inches from the top of plate C with the film package in intimate contact with the plate. The resulting negative will depict optimum detail obtainable with the source of gamma rays being qualified.

At this point it is necessary to discuss capsule arrangement. The capsule containing the radium salt or radioactive isotope usually is cylindrical in shape. The importance of capsule orientation must be understood by the inspector since improper capsule orientation will result in poor radiographic definition. Again quoting specification MIL-R-11470, it is stated that, "In determining the optimum value of d/t the radium source shall be arranged with its longest dimension perpendicular to the direction of the radiation that passes through the center of the test block, except that where the radium capsule is a cylinder the diameter of which equals its length, all dimensions of the cylinder shall be regarded as equal." The reasoning behind this requirement stems from the fact that the focal spot size of an isotope is equal to the physical area presented to the radiographic film. As in the case of X-ray machine sources, smaller focal spot sizes give the best definition. Thus, in the case of an isotope whose dimensions are not equal, the smaller dimension will give optimum radiographic definition. However, in this instance the intent of the specification is to examine the radiographic capability under the most adverse conditions; thus the longest isotope dimension is specified for qualification use. This means that the largest effective focal spot area must be employed.

TABLE I

Thickness of Steel to be Radiographed	Machine Rating (Kilovolts)
Not greater than 1"	140
Not greater than 2"	200
Not greater than 3"	220
Not greater than 3.5"	300
Not greater than 4"	400

TABLE II

Identification of Negatives	Relationships
2B1	d = 15" t = 3. d/t = 5
2B2	d = 30" t = 3. d/t = 10
2B3	d = 40" t = 3. d/t = 13
2B4	d = 50" t = 3. d/t = 17
2B5	d = 60" t = 3. d/t = 20

TABLE III

Identification of Negatives	Relationships	d/t
1B1	with t = 5" make d = 20"	4
1B2	with t = 2" make d = 20"	10
1B3	with t = 1" make d = 18"	18

TABLE IV

ISOTOPE AND RADIUM ENERGIES				
Element	Isotope	Half-Life	Approx. X-Ray Equivalent (MEV)	Energy (MEV)
THULIUM	TM-170	129 DAYS	0.1	0.08-0.96
IRIDIUM	IR-192	74 DAYS	0.3 - 0.4	0.10-0.60
CESIUM	CS-137	26 YEARS	0.66 MEV	0.66
COBALT	CO-60	5.3 YEARS	2 MEV	1.17-1.33
RADIUM	RA-226	1620 YEARS	0.7 MEV	0.2-2.2

MEV = MILLION ELECTRON VOLTS
1 MEV ≈ 1000 KV

TABLE V

Metal	50 KV	100 KV	150 KV	250 KV	400 KV	1 MEV	Gamma Rays
Magnesium	0.05	0.05	0.05	0.08			
Aluminum Alloys	0.08	0.08	0.12	0.18			0.35
Copper and Brass		1.50	1.50	1.40	1.40	1.25	1.10

The values appearing in the above table represent approximate radiographic equivalence factors using 1 as a base for steel and are intended solely for computation purposes in determining the steel thickness equivalence to be used for operator qualification.

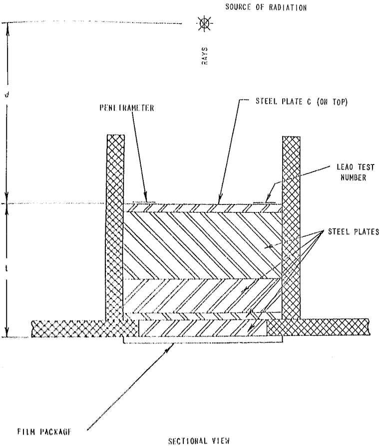


FIGURE 7. EXPOSURE 3A SET UP

Having made the comparison and test series radiographs, the optimum d/t ratio must then be selected. This is accomplished in the same manner as previously outlined for X-ray machines rated at 440 KV or less. This established value will be used in computing the working distance for the operator qualification portion of the test and for all subsequent production radiography.

c. Operator Qualification - The operator attempting qualification is permitted to make a reasonable number of attempts to secure a radiograph which he feels is adequate for submission. The qualifying term "reasonable" may be construed in terms of the amount of time that the District inspector feels he is justified in spending to witness the effort. When the operator is obviously incompetent, it is recommended that the District inspector conclude activities and suggest additional training. Whereas no submission to AMRA would be made under these circumstances, it is recommended that the District inspector document this attempted qualification for future reference in subsequent attempts and for use in establishing surveillance requirements.

1. X-Ray Equipment Rated at 440 KVP or Less - Operators are qualified after the selection of the optimum working distance has been made. As previously explained, the operator is responsible for all aspects of the radiographic technique and process including the selection of the radiograph which is submitted for evaluation. The cognizant District inspector should withhold all comments until the test radiograph is submitted, whereupon he should evaluate it to screen out obvious causes for rejection prior to submission to AMRA. Such obvious causes might be processing errors, failure to follow prescribed requirements regarding working distance, penetrameters, etc., and unsatisfactory image quality. The District inspector should make note of any such difficulties as they are indicative of the capability of the contractor and the degree of surveillance required.

The operator qualification test radiograph is identified as "3A." The following steps are required to produce this radiograph:

1. Ascertain maximum thickness of steel which will be radiographed according to the prevailing contract requirements.

2. Select sufficient thickness of plates from test block kit to construct the thickness required under "1". Plate K must be included and positioned on film side, i.e., at bottom of lead shield. Cracked plate C must be included and placed at source side, i.e., uppermost on plate stack. (See Figure 7)

3. Select proper penetrameter and identification symbols and position on cracked plate.

4. Select correct film system, working distance (being guided by optimum d/t ratio), kilovoltage, time, position setup and exposure.

5. Process film.

6. Evaluate with respect to adequacy of quality for submission.

Specification MIL-R-11470, paragraph 3.1.3.2 requires the image details of the penetrameter to be sharply defined. To assist the District personnel in appraising this condition the following explanation is offered: image detail is sharply defined when the outline of the penetrameter is discernible and the 2T hole is identifiable without question as a round hole when viewed under normal conditions without the aid of magnification. The relative adequacy of the crack image may be determined to a degree by comparing to the comparison radiograph taken under equipment qualification. Correct practical evaluation of the crack image by the contractor or the District personnel is not possible. This particular phase of the qualification procedure is accomplished at AMRA by the use of standard radiographs of each crack image.

2. X-Ray Equipment Rated at 1000 KV - Operator qualification using X-ray machines rated at 1000 KV is performed in essentially the same manner as the lower energy machines. However, two radiographs are required. Note that no identification is cited for these two radiographs. The penetrameter image will indicate thickness. Operator's initials are suggested as a basic identification and the working distance is established as a minimum requirement only. In addition, because of the greater possible thickness of steel to which qualification can be made (7 inches maximum), the effective shielding afforded by the test block kit is inadequate. The operator is thus presented with the additional requirement of developing necessary shielding from secondary, scattered radiation. The basis for requesting two test radiographs lies in the fact that two are needed to present the maximum of technical challenge. High energy radiography with the attendant lower contrast and greater shielding requirements render radiography of thin sections as difficult as that of the maximum thickness. The selection of optimum working distance has been discussed previously.

3. Gamma Ray Equipment - Operator qualification for gamma radiography is accomplished by producing one radiograph. This test radiograph is identified as 2A. A steel thickness of 3/4 - inch is specified for all operator tests involving gamma ray sources.*

The use of a single test exposure at a single established thickness is based upon the fact that the radiation from an isotope source is composed of a few specific energies rather than the spectrum of energies produced by an X-ray machine. Under these conditions the selective absorption of the test specimen with respect to radiation energy is of minor importance and the effect of subject thickness upon radiographic quality is lessened. Coincidentally, however, the ability to detect flaws which is contingent upon contrast quality becomes critical due to the lack of the lower energy radiation. This effect is particularly prominent when the subject thickness is small. The selection of a 3/4-inch test specimen thickness is a compromise predicated upon the characteristics of the several induced isotopes, which are commonly used, and radium.

The performance of the operator qualification test is similar in other respects to the requirements cited for machine X-ray sources. The operator is charged with selecting all factors of the radiographic exposure. The test subject must include plate C, positioned on the source side, and plate K positioned on the film side. Plate D and either plate E or J added to plates C and K will make the required 3/4-inch thickness. Identification symbols and a 3/4-inch type penetrameter must be employed. The operator alone should be required to determine if his radiograph is suitable for submission.

Reporting of Test Results - The reporting of radiographic qualification test data must be accomplished in a systematic manner, with all pertinent information and details surrounding the test properly recorded This point must be emphasized, since evaluation at AMRA of any qualification test will be based solely upon the required radiographs and the technical data submitted. Supplemental data sheets have been developed for this purpose and it is strongly recommended that each district use them. These data sheets (see Figure 2) should be employed where applicable, not only to facilitate reporting of essential technical data, but

*Thulium 170 is excepted from this requirement. The low inherent energy of this isotope (Table V) would make the radiography of 3/4-inch of steel a difficult task. Since Thulium 170 is used principally for light alloy and thin material radiography it is recommended that the operator qualification test be omitted (waived) and instead the capability of the operator be evaluated upon his ability to radiograph a subject similar to that anticipated in contract work. The equipment qualification phase of testing should be accomplished. It is suggested that the report of test to AMRA include the substituted radiographic test exposure with a statement of evaluation by the District.

also to effect a degree of standardization in data reporting. The sheets shown in Figure 2 are suitable for both X-ray and gamma ray qualification reporting. The front side of each type essentially requires information pertaining to the following:

1. Identification of the machine or source.

2. Radiation Safety

3. Selected optimum d/t ratio

4. Material kind and thickness

5. Facility requesting qualification

6. Statement of Government Inspector

7. Remarks

The back side of each form requests information pertinent to the radiographic technique employed and the name of the operator attempting qualification. Each item in the data sheets should be completed if possible. The radiographs and technical data sheets shoud be carefully packed for transmittal since the condition in which the radiographs are received at AMRA will affect evaluation. A brief cover letter and the inclosures are then forwarded to U. S. Army Materiels Research Agency AMXMR-TMT.

SURVEILLANCE OF PRODUCTION ACTIVITIES

The latitude of Specification MIL-R-11470 is sufficiently broad so that surveillance is permissible and highly desirable. No hard and fast surveillance programs can be established which will fit each case, since each contractor and the type of work involved will necessarily dictate surveillance requirements. The following recommended procedures are offered for the guidance of the inspector:

1. Production planning phase visit to insure cognizance or radiographic inspection plans. A clue indicating the depth of the contractors inspection plan may be revealed by noting if provisions have been made for re-radiography after repair.

2. Visitation shortly after beginning of production for purposes of noting implementation of radiographic inspection plans.

3. The frequency of future visitations may be predicated upon:

   a. Product complexity

   b. Preciseness requirements

c. Production volume and rate

4. Attendant factors which should be considered:

a. Change in design which may necessitate a change in fabrication methods and/or materials and thereby affect radiographic inspection.

b. A change in radiographic personnel or equipment.

5. The receipt of new contracts by vendors will require a review of existing qualification if a new product is involved. Such a situation would arise if a facility held a qualified status for thicknesses up to 2 inches of steel but were required to radiograph 2-1/2 inches by virtue of a new product. Requalification would of course be necessary. The Procuemen District inspector would also note the adequacy of the equipment in performing the radiography required for the new product.

REQUALIFICATION REQUIREMENTS

Requalification is required under any of the following conditions:

a. Installation of a new tube in radiographic equipment previously qualified. Reference to this point is made in Paragraph a, page 142. Both operator and equipment should be requalified.

b. Equipment and operators qualified to radiograph a given thickness would be required to requalify if this thickness were increased. Only operator qualification phase need be undertaken as the equipment characteristics are not affected.

c. In such cases where qualification was revoked and it is desired to re-establish qualification, complete requalification is required.

d. In such cases where the Procurement District has reason to believe that requalification is advisable and in the best interest of the Government. For example, if the quality of radiographic inspection becomes substandard it may be desired to revoke existing qualification. The decision initiating this action is made by the cognizant District.

e. Replacement of an isotope source will be assumed to require requalification. Qualification of the new source may be waived if it is identical in size, shape and type to that source which is being replaced and which was previously qualified.

No requalification frequency is established and it may be correctly assumed that an original qualification remains in force so long as the quality of radiographic inspection is satisfactory and the need for radiography to Government Specifications prevails. The responsibility for determining the need for requalification lies wholly with the Districts which are in closest contact with contractors. It is recommended that

reviously qualified installations be resurveyed and the need for requalification be evaluated whenever a period of 30 days lapses between active irsuit of Government contracted inspection effort.

ADMINISTRATIVE REQUIREMENTS

The contractor should be informed by the inspector that the District ily should deal with AMRA in obtaining information regarding the status pending qualification tests. Contractors have attempted to deal rectly with AMRA only to be told that they must contact the District volved. Instances have arisen where the cognizant Procurement istrict has felt that a telephone conversation between the contractor d AMRA would prove beneficial. Direct telephone contact will be cepted only after such contact has been established by the District, and District representative monitors such conversations. Contact of this ture must be confined to technical factors concerning radiography

No certification forms for contractors facilities or operators are ed or issued. Certification is effected by official correspondence tween AMRA and the cognizant Procurement District. The qualification test negatives and copies of associated technical data sheets together th pertinent correspondence are kept on file at AMRA. However, in ses of disqualification, the submitted radiographs and data sheets are turned.

INTERIM QUALIFICATION

The Procurement District may grant interim clearance (permission) perform radiographic inspection. This action would be predicated upon e fact that delay or interruption of production would adversely affect the st interest of the Government. However, interim clearance should be anted only on the basis that the technical ability of the contractor apars to justify such action. At the minimum, a contractor capability rvey should be performed and prior record of performance, if any, aluated. Preferably, the radiographic qualification test whould be rformed first and evaluated by District personnel. Interim clearance ould be the exception and not customary procedure.

QUALIFICATION OF GOVERNMENT FACILITIES

Although the radiographic qualification of Government operated ilities is not specified, it would be educational and beneficial for those ilities to meet the same standards required of government contractors ch qualification is recommended.

WAIVERS

The granting of waivers by the Districts other than those specifically ecified in MIL-R-11470, should be considered on a technical basis and y when proper justification by the contractor is provided. The burden proving the technical adequacy of procedures to be used under waived cumstances lies with the contractor.

TRAINING PROGRAM FOR QUALIFICATION PROCEDURES

As part of the Metals Inspection and NondestructiveTesting Training Program conducted by Watertown Arsenal, a special course in radiography is provided. The objective of this course is to provide experienced metals inspection personnel with the knowledge of up-to-date radiographic techniques and to assist them in applying and intelligently interpreting radiographic specifications, standards and qualification procedures. While this course does not deal strictly with radiographic qualification, it is recommended for inspection personnel who are required to administer the qualification test. Particulars and a training brochure are available.

TECHNICAL ASSISTANCE

Technical assistance by AMRA is provided on an "as requested" basis in the field of nondestructive testing to the Procurement Districts.

QUALIFICATION OF METALS OTHER THAN STEEL

The scope of Specification MIL-R-11471 states that, "This specification covers the procedure to be used in radiographic inspection of metals. Radiographic qualification therefore is not restricted to steel only, but must include other metals which, when specified, whould be subject to the full requirements of MIL-R-11470. It is recognized that the present qualification test has been designed primarily for steel. However, where radiography of metals other than steel is involved, radiographic equivalence factors are employed to compute the equivalent thickness of steel for which qualification should be sought. In other words, if a thickness of 5 inches of aluminum is encountered in a government contract, qualification is accomplished by first selecting the approximate radiographic equivalence factor (see Table V) for aluminum based upon the kilovoltage to be employed. This factor is multiplied by the aluminum thickness, the product of which gives the equivalent steel thickness. For example, qualification for 4 inches of aluminum is sought using 150 KV equipment. According to Table V the radiographic equivalence factor for aluminum at 150 KV is equal to 0.12. This factor (0.12) is multiplied by the thickness (4 inches) which means that in the operator qualification portion of the test, the block must be built up to 0.48 or 0.50 inches of steel. This figure should be adjusted to the nearest 1/8 inch. Upon the successful completion of a qualification test conducted in the above manner, notification by AMRA to the District will state that the facility in question is qualified to perform industrial radiography up to and including a thickness of 4 inches of aluminum. Summarizing, the complete qualification test is performed according to Specification MIL-R-11470, but instead of normally using the thickness which will be encountered in the production contract for the operator qualification portion, an equivalent thickness of steel isemployedwhich is radiographically equivalent to the thickness of the production material. The machine qualification is conducted in the conventional manner.

SAFETY OF GOVERNMENT PERSONNEL

It is the prerogative of the cognizant Procurement District to require that authoritative documented evidence be furnished by the Atomic Energy Commission (AEC), State Board of Health, or a qualified expert concerning the prevailing radiation safety conditions of a given private facility. This action should be taken prior to or during the initial visit by Government personnel. Such evidence should include proof that the facility has been surveyed and found to be free from ionizing radiation of a level sufficient to be harmful to personnel. In this way the District can assure itself that District personnel are relatively safe when conducting operations at these facilities. The qualifications of the facility should be posted stating whether the area is fully safe or conditionally acceptable and requiring special precautions such as radiation beam orientation or safe operating distances, etc. It should be noted also that standard safe operating procedures should be posted and must state that the radiation protection barriers have been constructed for the safe operation of all radiation sources that are being used therein. Any increase in radiation energy will require a resurvey to determine adequacy of the protective barriers. Radium should be handled in the same manner as radioactive isotopes even though radium does not require an AEC license. Radium used for industrial radiography is potentially as hazardous as other radiation producing sources and should be used according to established standard safe operating procedures. An indication of an adequate radiation safety program is the wearing of personnel monitoring devices such as dosimeters and film badges by contractors radiographic personnel. In summary, X- and gamma radiation are invaluable inspection tools and are harmless to personnel when proper precautions are taken. Therefore, it behooves all Government employees to exert the necessary effort to assure their own safety by insisting upon safe practices by the contractor. It is recommended that the District incorporate radiation safety in the indoctrination program for personnel concerned with radiographic inspection.

GLOSSARY OF TERMS USED IN RADIOGRAPHY

ABSORPTION - The dissipation of radiation energy by the scattering process within a material as the radiation passes through the material. (See SCATTER)

ABSORPTION LAW - At a given wavelength for a homogeneous material, each equal layer of the material absorbs an equal fraction of the radiation incident on that layer.

ABSORPTION COEFFICIENT, LINEAR - The fractional decrease in transmitted intensity per unit of absorber material. It is designated by the symbol μ.

ACTIVITY/UNIT WEIGHT - See SPECIFIC ACTIVITY

ALTERNATING CURRENT - Electric current that is periodically reversing in polarity or direction of current flow. (See DIRECT CURRENT)

ANGSTROM (Å) - Unit of length usually reserved for expressing wavelength. One angstrom equals 10^{-8} cm. (3.937×10^{-9} in.)

ANODE (TARGET) - The positive terminal of an X-ray tube. It is a high melting point element and receives the electron bombardment from the cathode or negative terminal.

ARTIFACTS - Inherent false blemishes produced during the manufacture, packaging, handling, or processing of the film. They appear as white or black crescents, fogging, staining, etc.

ATOM - The smallest part of an element. It consists of a nucleus composed (with the exception of hydrogen) of a number of protons and neutrons. Included also is an extranuclear portion composed of electrons equal in number to the nuclear protons. The hydrogen atom consists of a nucleus of one proton with one extranuclear electron.

ATOMIC NUMBER - An integer that expresses the positive charge of the nucleus in multiples of the electronic charge. In present theory, it is the number of protons in the nucleus and is also equal to the number of electrons outside the nucleus of a neutral atom.

ATOMIC REACTOR - An atomic furnace in which the nuclei of the reactor fuel undergoes a process of fission under the influence of neutrons. The fission produces new neutrons, and thereby, a chain reaction which results in the release of large amounts of energy usually removed from the reactor in the form of heat.

ATOMIC WEIGHT - The relative weight of the atom of an element, referred to some element taken as a standard. An atomic weight of 16 for oxygen is the one usually adopted as a basis for reference.

AUTOTRANSFORMER - A special type of transformer in which the output voltage can be easily varied. The autotransformer is thus employed to adjust the primary voltage applied to the step-up transformer which produces the high voltage applied to the X-ray tube.

BACKGROUND RADIATION - Radiation coming from sources other than radioactive material, primarily due to cosmic radiation emitted fron outer space.

BACKSCATTER - The deflection of scatter radiation at angles greater than 90° with respect to the original direction of motion.

BARIUM CLAY - A molding clay blocking material containing barium, used to eliminate or reduce the amount of scattered or secondary radiation reaching the film.

BETA PARTICLE - A small electrically charged particle thrown off by a radioactive disintegrating nucleus during its decay cycle. It is identical with the electron and possesses the smallest negative charg found in nature.

BETATRON - A large doughnut-shaped accelerator in which injected electrons are whirled through a changing magnetic field gaining spee with each acceleration cycle. The betatron is a source of high speed electrons which can be made to impinge upon a target to produce X-rays or can be used for research purposes.

BLOCKING (MASKING) - The various methods that are employed by radiographers to reduce or eliminate scattered radiation; for exampl masking with lead, barium clay, metallic shot, and liquid absorbers

BUNSEN-ROSCOE RECIPROCITY LAW - States that the end result of a photochemical reaction is dependent only on the product of the radiation intensity (I) and the duration of the exposure (t), and is independ of absolute values of either quantity. This implies that the resultant density of a film would depend only on the product of the radiation intensity reaching the film and the exposure time.

CALCIUM TUNGSTATE - A fluorescent chemical compound which emits visible blue-violet light when activated by either X- or gamma radiation.

CASSETTE - A lightproof container used for holding the radiographic films in position during the radiographic exposure. It may or may not contain intensifying and/or filter screens.

ATHODE (FILAMENT) - The negative terminal or an X-ray tube which emits the electrons essential for the bombardment of the anode to generate X-rays.

ATHODE RAY - A ray of electrons emitted by a cathode and projected in a beam.

:ESIUM 137 - A radioactive isotope of the element cesium having a half-life of 30 years, plus or minus three years.

:HARACTERISTIC CURVE - A sensitometric curve expressing the relationship between the exposure applied to a photographic material and the resulting photographic density.

OBALT 60 - A radioactive isotope of the element cobalt having a half-life of 5.3 years and extensively used in research and as a source of gamma radiation.

OLLIMATER - A device, usually made of lead, used to surround a radiation source and so constructed as to both minimize the scattered radiation and to direct and concentrate the primary or useful radiation into a more or less parallel beam onto a localized area.

OMPTON EFFECT - The glancing collision of an X-ray or gamma ray with an electron resulting in a gain of energy for the electron.

ONE - A lead diaphragm or cone placed on the tube head to concentrate the X-ray beam conically on a limited area. These lead diaphragms are especially useful where the desired cross-section of the X-ray beam is a simple geometrical figure, for example, a circle, square or a rectangle.

ONTRAST, RADIOGRAPHIC - The measure of difference in the film blackening resulting from various X-ray intensities transmitted by the object and recorded as density differences in the image. Thus, difference in film blackening from one area to another is contrast.

ONTRAST SENSITIVITY - The degree of sharpness evidenced by the detail of the outline of the penetrameter. If the outline is clearly defined, the contrast sensitivity is referred to as 2 percent or better

OUNTER - A device for counting nuclear disintegrations to measure radioactivity. The signal which announces a disintegration is called a count and is measured in counts per second (cps).

URIE - A unit of measure to express the rate at which a quantity of radioactive material decays. It is that quantity of material in which 3.70×10^{10} disintegrations per second are taking place. The rate of disintegration of 1 gram of radium (i.e., radon in radioactive equilibrium with 1 gram of radium) was the original basis for the curie since its disintegration rate was approximately 3.70×10^{10}

per second, but the unit has now been standardized by an international committee as any quantity of material having this decay rate.

CUTIE-PIE - A colloquial term applied to a portable instrument equipped with a direct reading meter used to determine the level of radiation in an area. (See COUNTER)

CYCLOTRON - A particle accelerator in which the atomic particles are whirled around in a spiral between the ends of a huge magnet gaining speed with each rotation. The cyclotron is normally used for nuclear research but the particles can be made to collide with a target to produce X-rays.

d/t RATIO - The working distance for the X-ray tube in relation to the film distance. The working distance, d, and the specimen thickness, t, are both measured with reference to the source side of the specimen.

DECAY, RADIOACTIVE - Spontaneous change of a nucleus with emission of a particle or a photon. For a definite quantity of a nuclide, the rate of decay is usually expressed in terms of half-life.

DECAY CURVE - A graph used in radioisotope radiography to determine the compensation or correction for the exposure time based on the known half-life of the radioisotope being used.

DEFECT - A discontinuity which affects the usefulness of a part, or a fault in any material which is detrimental to its serviceability. (See FLAW)

DEFINITION, RADIOGRAPHIC - The degree of sharpness with which the radiograph outlines any discontinuities or abrupt geometrical changes.

DENSITOMETER - An instrument that is used to determine the photographic density indicated on a radiograph.

DENSITY, RADIOGRAPHIC - The degree of blackening of a film is density. Film blackening or density is usually expressed in terms of the H & D (Hurter and Driffield) curve which is defined as the logarithm of the reciprocal of the transparency of the film. Blackening equals log 1/T (T = Light Transmission).

DENSITY GRADIENT - The change in density of a radiographic film per unit change in the logarithm of the exposure received by the film. The maximum density gradient of a film is usually called gamma.

DESENSITIZATION - An effect on the emulsion of a radiographic film caused by pressure of any type exerted on the emulsion prior to exposure. A desensitized area on a film is characterized by low density in the affected area.

DETAIL - The degree of sharpness of outline of the image. If the radiograph does not show a clear definition of the object or a discontinuity in the object, it is of little value although it may have sufficient contrast and density.

DETAIL SENSITIVITY -The radiographic definition or sharpness of detail as indicated by the drilled holes in a penetrameter. The normal penetrameter sensitivity level for an acceptable radiograph is generally spoken of as having 2 percent detail sensitivity. (The 2T of a drilled hole in a penetrameter of a thickness of 2 percent of the overall material thickness being radiographed).

DIRECT CURRENT - An electric current which is termed unidirectional, because it flows steadily in one direction. (See ALTERNATING CURRENT)

DIRECT RADIATION - That portion of the primary radiation which passes through the material being radiographed in an undeflected form.

DISCERNABLE IMAGE - Image capable of being recognized by sight without the aid of magnification; corrected vision excepted.

DISTORTION - Any deviation from the normal shape of an object.

DOSE - The quantity of radiation delivered to a specified mass or volume. The dose unit of interest to the radiographer is the roentgen (r).

DOSIMETER - An ionization chamber which is electrically charged and from which the amount of discharge in milliroentgens may be noted by the wearer as desired, actually, a "dose meter" which indicates the radiation dosage a person has received in a radiation area.

DUPLITIZED FILM - Radiographic film which consists of a coating of photosensitive emulsion on both sides of the tinted cellulose acetate safety base.

ELECTROMAGNETIC SPECTRUM - The wavelength range of the various forms of electromagnetic radiation.

ELECTROMOTIVE FORCE (emf) - The work or energy which causes the flow of an electric current and expressed as volts.

ELECTRON - One of the fundamental constituents of atoms. The tron is a very small negatively charged particle with a rest approximately 1/1836 that of the hydrogen atom, or 9.107 x It has an electric charge of 4.802 x 10^{10} statcoulomb (the el static unit of charge). Electrons appear to be uniform in m charge.

ELECTRON VOLT - A small unit of energy expressed as "ev". An electron gains this much energy when it is acted upon by one volt.

ELECTROSTATIC GENERATOR - A type of generating equipment which supplies high voltage by static negative charges conveyed mechanically to an insulated electrode usually by means of a rotating belt.

ELEMENT - A class of atom having a particular atomic number as its distinguishing characteristic. Also, a substance having atoms of the same atomic number, or a naturally occurring mixture of isotopes. Oxygen, carbon, and uranium are examples.

EMULSION - The gelatinous substance in which is dispersed fine grains of silver halide crystals used to coat the cellulose acetate base of an X-ray film.

ENERGY, RADIOGRAPHIC - The characteristic that determines penetration and absorption of radiation. It is generally measured in thousands or millions of electron volts - kev or mev.

ENLARGEMENT - See MAGNIFICATION

EQUIVALENCE FACTORS - What the thickness of a given metal is to be multiplied by to obtain the approximate equivalent thickness of a standard metal. (The standard metal is aluminum up to 100 kilovolts and steel for higher voltages and gamma radiation.)

EVALUATION - Determining whether the flaws or discontinuities as indicated on a radiograph are cause for rejection of the part, or whether the part is either repairable or can be used as is.

EXPOSURE CHART - A graph showing the relation between material thickness, kilovoltage, and exposure. It is only adequate for determining exposure time for uniform thicknesses of material.

EXPOSURE FACTOR - A quantity that combines milliamperage or source strength, time, and distance. Numerically, the exposure factor for X-rays equals the product of the milliamperes and time divided by the square of the distance. For gamma rays, the exposure factor equals the product of the millicuries and time divided by the square of the distance.

EXPOSURE - The product of the X-ray intensity in milliamperes and the time in seconds or minutes which governs the photographic density of a radiograph. For radioactive sources, the product of curies or millicuries and the time in minutes or hours.

FAST FILM - Radiographic film which has inherent graininess characteristics of a coarse nature intended to increase the relative film speed. (See RELATIVE SPEED.)

FILAMENT - See CATHODE

FILM BADGE - A piece of masked radiographic film worn in the form of a badge. The amount of exposure can be checked by the degree of darkening apparent after processing the film.

FILM CONTRAST - The degree of contrast contributed by the graininess characteristics of the radiographic film itself. A fine grain film generally results in a high contrast and a coarse grain film in a low contrast.

FILM SPEED - A relative term expressing the difference in exposure times required to radiograph the same object and obtain similar results using different types of X-ray film.

FILTER - A layer of absorptive material which is placed in the beam of radiation for the purpose of absorbing rays of certain wave lengths and thus control the quality of the radiograph.

FILTRATION, FILM - The filtering effect provided by lead foil intensifying screens to reduce scatter or secondary radiation. The longer wavelengths of the scatter or secondary radiation are absorbed by the lead, and the resultant definition on a radiograph is greatly improved.

FILTRATION, INHERENT - The filtration due to the walls of the X-ray tube and other materials used to contain a radiation source through which the radiation must pass before it is utilized.

FILTRATION, TUBE HEAD - A process wherein the use of an absorptive filter, such as copper, placed at the tube head, reduces excessive subject contrast by hardening the radiation. This tube head filtration absorbs the longer wavelengths and only allows the shorter wavelengths to pass through.

FIXING - The procedure in film processing that removes all of the undeveloped silver salts of the emulsion from the surface of the film, thus leaving only the developed latent image.

FLAW - An imperfection in an item or material which may or may not be harmful. (See DEFECT.)

FLUORESCENCE - The emission of electromagnetic radiation by a substance as the result of the absorption of electromagnetic or corpuscular radiation having greater unit energy than that of the fluorescent radiation. Fluorescence is characterized by the fact that it occurs only so long as the stimulus responsible for it is maintained. The characteristic X-radiation emitted as a result of absorption of X-rays of higher frequency is a typical example of fluorescence.

FLUORESCENT SCATTER - Long wavelength monochromatic radiation given off by the specimen in all directions when struck by primary radiation.

FLUORESCENT SCREENS - Intensifying screens composed of fluorescent salts (e. g., calcium tungstate), which emit a visible blue-violet electromagnetic radiation when activated by the absorption of the primary rays, thereby reducing the exposure time.

FLUOROSCOPY - The visual presentation of an X-ray image on a fluorescent screen.

FOCAL-FILM DISTANCE - The distance between the focal spot of an X-ray tube or radiation source and the film, generally expressed in inches.

FOCAL SPOT - The area on the target which receives the bombardment of electrons and emits the primary radiation necessary to produce an image of the object on a radiographic film.

FOGGING - A darkening of a film which can result from the chemical action of a developer, aging, scattered secondary radiation, pre-exposure to radiation, or exposure to visible light.

FREQUENCY - The number of completed cycles per unit of time, for example, 60 cycles per second.

GAMMA RAYS - Electromagnetic radiation of high-frequency or short wavelength emitted by the nucleus of an atom during a nuclear reaction. Gamma rays are not deflected by electric or magnetic fields. They are identical in nature and properties, to X-rays of the same wavelength.

GEIGER COUNTER - A gas-filled electrical device which detects the presence of radioactivity by counting the formation of ions.

GELATIN - See EMULSION

GEOMETRIC FACTORS - The factors governing the gometry of a part insofar as the proper working distance is concerned. The proper d/t ratio preserves spatial relationships, prevents enlargement, and reduces distortion.

GRAININESS - A film characteristic which consists of the grouping or clumping together of the countless small silver grains into relatively large masses visible to the naked eye or with slight magnification.

HALATION - The fogging of a film emulsion due to reflection and dispersion of the radiation within the emulsion. This is generally apparent at locations of heavy exposure.

HALF LIFE - The time required for the intensity of a radioisotope to be reduced to one-half of its original value.

HALF-VALUE LAYER - The thickness of a material which transmits 50 percent of the radiation incident upon it. In exponential attenuation, the half-value layer, is related to the linear attenuation coefficient and the mean free path.

HARDENER - An agent incorporated into the fixer solution to harden the emulsion during the fixing process. The acid hardener prevents the swelling of the emulsion and facilitates the drying process.

"HARD" X-RAYS - A term used to express the quality or penetrating power of X-radiation. Hard X-rays are very penetrating. (See QUALITY and SOFT X-RAYS.)

HAZINESS - See FOGGING

H & D CURVE (Hurter and Driffield) - See CHARACTERISTIC CURVE

HIGH CONTRAST - Photographic densities that are very dark in contrast to those that are very light caused by the geometry of the object being radiographed and indicated on the radiograph.

HIGH INTENSITY ILLUMINATOR - A variable intensity type of illuminator which is capable of penetrating densities as high as 4.0 or any lower density that may be represented on a radiograph.

N-MOTION RADIOGRAPHY - A method in which either the object being radiographed or the source of radiation is in motion during the exposure.

NTENSIFYING FACTOR - The ratio of the exposure using intensifying screens to the exposure without the screens that produces the same photographic density on a radiograph.

NTENSIFYING SCREENS - Any layers of material used in combination with a film to reduce the exposure time by means of intensification of the primary radiation (e.g., lead foil and calcium tungstate screens).

NVERSE SQUARE LAW - At constant kilovoltage or source strength, the intensity of the radiation reaching the object is governed by the distance between the focal spot or radioactive source and the object, varying inversely with the square of this distance.

ON - A particle bearing an electric charge which is formed wh
neutral atom, or molecularly bound group of ato
one or more electrons. Loss of electrons resu
charged particles called cations; gains of elect
or negatively charged particles. Ions, in ra
formed by the action of radiation on gas molucules. This phenomenon is of particular importance when using ionization chambers for radiation detection, and when trying to eliminate air ionization in the Xero-radiographic process.

IONIZATION CHAMBER - A device roughly similar to a Geiger counter and used to measure radioactivity.

IRIDIUM 192 - A radioactive isotope of the element Iridium which has a half life of 75 days. It is used extensively as a source of gamma radiation.

ISOTOPE - One of several nuclides having the same number of protons in their nuclei, and hence belonging to the same element, but differing in the number of neutrons and therefore in mass number. Small quantitative differences in chemical properties exist between elements and isotopes. (See NUCLIDE)

KILOCURIE - A unit of radioactivity equal to 1,000 curies.

KILOVOLT (kv) - A unit of potential or electromotive force equal to 1,000 volts. The voltage governs the penetrating quality of the radiation; the higher the voltage the more penetrating the radiation.

KILOVOLT PEAK (kvp) - The crest value, peak, or highest point of the voltage wave form that is applied to the X-ray tube.

LATENT IMAGE - The metallic silver image of the material radiographed brought out by the developing process.

LATITUDE, RADIOGRAPHIC - Latitude, most closely aligned with contrast, is commonly called the "scale" of the film. Latitude is the range of thickness of material that can be transferred or recorded on the radiograph within the useful reading range of film density. A high contrast film has little latitude and conversely a low contrast film has great latitude.

LINE FOCUS PRINCIPLE - The process of making the angle between the anode face and the central ray such that the effective focal spot is small in relation to the actual spot size.

LINEAR ACCELERATOR - An apparatus used to accelerate electrons to high velocities by means of a high frequency electrical wave traveling along a tube in the linear direction of the electron beam.

MAGNIFICATION - The degree of enlargement of an object that is not in intimate contact with the film and screen. It includes the enlargement of those parts of the object furthest from the film.

MASKING - See BLOCKING

MASS ABSORPTION COEFFICIENT - The linear absorption coefficient divided by the density of the material; generally recorded in tables for the different elements.

MICROAMPERE - A unit of current equal to one one-millionth of an ampere.

ICRORADIOGRAPHY - The radiography of objects or specimens that are only a few thousandths of an inch thick. A regular radiograph is first made on fine grain film and then enlarged as much as 300 times.

ILLI - Prefix meaning one one-thousandth; e.g., a millirad equals one one-thousandth of a rad.

IOLECULE - When atoms combine they form a molecule. In the case of an element or compound, a molecule is the smallest unit which still retains the chemical properties of the substance in mass.

IONITOR - A radiation detector used to determine if an area is safe for personnel.

OTTLING - Large graininess effect on a radiograph caused by the use of fluorescent intensifying screens. Readily distinguishable from film graininess because of its coarse mottled appearance and lack of definition and detail.

EUTRON - An uncharged particle of the nucleus of an atom whose mass is very nearly equal to but slightly greater than the mass of a proton.

JCLEUS - The heavy central part of an atom in which most of the mass and the total positive electric charge is concentrated. With the exception of the nucleus of hydrogen, nuclei are composed of protons and neutrons. The charge of the nucleus, an integral multiple of the charge of the electron, is the essential factor which distinguishes one element from another chemically.

JCLIDE - A species of atom characterized by the constitution of its nucleus; in particular by the numbers of protons and neutrons in its nucleus.

IR FORMATION - The conversion of very high-energy photons, when absorbed in matter, by a process wherein the photon is converted in the electrical field of a nucleus into an electron (negative charge) and a positron (positive charge).

NETRAMETER, RADIOGRAPHIC QUALITY - A piece of metal of the same composition as that of the metal being tested, representing a percentage of object thickness and provided with a combination of steps, holes, or slots. When placed in the path of the radiation, its image provides a check on the radiographic technique employed.

NETRATION - The quality of the radiation as determined by the wavelength. The higher the voltage, the more penetrating the radiation because of the shorter wavelength rays employed.

NUMBRA - The shadow cast when the incident radiation is partly, but not wholly, cut off by an intervening body; the space of partial illumination between the umbra, or perfect shadow, on all sides and the full light. A marginal region or borderland of partial obscurity.

PHOTON - An electromagnetic packet of radiation. It has a dual character, acting sometimes like a particle and at other times like a wave. Photons all have equal velocity (the speed of light), have no electric charge, and have no magnetic moment.

POSITRON - A fundamental particle of nature having a mass equal to that of the electron and possessing a positive charge equal to the negative charge of the electron.

PRIMARY RADIATION - Radiation coming directly from the target of an X-ray tube or from a radioactive source.

PROTON - An elementary particle of nature having a mass of 1.00758 atomic mass units (1 atomic mass unit equals 1.66×10^{-24} gm) and possessing a positive charge of the electron (4.802×10^{-10} statcoulomb). The mass of the proton equals the mass of the hydrogen atom less one electron. The proton is one of the constituents of all atomic nuclei.

QUALITY, RADIATION - An expression relating to the penetrating power of radiation. It is a function of the wavelength of radiation. The higher the X-ray tube voltage, the shorter the wavelength radiation produced and hence the more penetration, or greater the quality, of the X-rays. (See also HARD-RAYS and SOFT-RAYS).

RAD - A unit of absorbed radiation dose. It is defined as the dose corresponding to the absorption of 100 ergs per gram of irradiated material.

RADIOACTIVE DECAY - The spontaneous nuclear disintegration of a material. It occurs on an atomic scale by the loss of subatomic particles (i.e. protons, neutrons, electrons, etc.). (See HALF-LIFE, RADIOISOTOPES, and RADIOACTIVITY).

RADIOACTIVITY - Spontaneous nuclear disintegration with emission of corpuscular or electromagnetic radiations. The principal types of radioactivity are alpha disintegration, beta decay (electron emission, positron emission, and electron capture) and isometric transition.

RADIOGRAPH - A photographic record produced by transmitting radiation through material and recording the soundness characteristics of the material on film especially made for this purpose.

INTERPRETATION - The determination of the cause ce of subsurface discontinuities indicated on the radiograph. The evaluation as to the acceptability or rejectability of the material is based upon the judicious application of the radiographic specifications and standards governing the material.

RADIOGRAPHIC QUALIFICATION TEST - A procedure for determining the optimum value of the d/t ratio, or the proper working distance of an X-ray tube or a radioactive source.

RADIOGRAPHIC TECHNIQUE - The selection of those radiographic factors such as kilovoltage, milliamperage, type of film and screen, distance and exposure time as to render the best possible radiographic sensitivity.

RADIOGRAPHY - A nondestructive testing method wherein a source of X-rays, or gamma rays, is utilized to indicate the subsurface condition of opaque materials. A permanent record of the soundness characteristics is generally made on specially prepared film called the radiograph.

RADIOISOTOPE - A radioactive isotope of an element which can be produced by the placement of the material in a nuclear reactor and bombarding it with neutrons. (See ISOTOPE)

RADIUM - A naturally occurring radioactive element which has a half-life of about 1620 years. It is far more radioactive than uranium although generally found in the same ores.

RADON - A radioactive gas emitted during the disintegration of the radium muclei and usually confined in the sealed portion of the radium pill. It possesses a relatively short half-life value of about 3.85 days.

RATE METER - A device designed to measure radiation per unit time, as in milliroentgens per hour. It is used for detecting radiation fields and measuring the exposure rate.

RBE (RELATIVE BIOLOGICAL EFFECTIVENESS) - The ratio of doses from two different radiations that produce the same biological change

RECTIFIER - A tube or circuit capable of converting the high voltage alternating wave form into a usable unidirectional voltage wave form.

RELATIVE SPEED - The exposure time of any radiographic film relative to one particular type of film whose speed is arbitrarily assigned a value of 100.

REM (RAD OR ROENTGEN EQUIVALENT MAN) - The absorbed dose in rads multiplied by the relative biological effectiveness (RBE) of the radiation used on the particular biological system irradiated. The REM is the currently accepted unit of radiation dose to biological systems.

ROENTGEN (r) - The international unit of the quantity of X- or gamma rays such that the associated (corpuscular) emission per 0.001293 gram of air produces, (in air), ions carrying 1 electrostatic unit (esu) of quantity of electricity of either sign. It is usually employed to express the radiation output of a given source in terms of roentgens per hour at one meter (rhm).

.AFELIGHT - A special lamp used in the darkroom to provide working visibility without affecting the photosensitive emulsion of the radiographic film.

;CATTER - One of the causes of haziness or fog. Some of the incident radiation is scattered by atomic electrons of the object being radiographed much as light is dispersed by fog. Any material, whether specimen, cassette, table top, walls, floors, etc., receiving direct radiation, is a source of scattered radiation.

;CATTER, MODIFIED- A scattering process within the material whereby the original X-ray photon collides with an electron comprising the material with a resultant increase in wavelength.

;CATTER UNDERCUT - A type of secondary radiation evidenced with X-ray machines of limited kilovoltage up to 400 Kv, wherein the exposed areas of a radiographic film tend to become hazy or foggy. Parts which do not make intimate contact with the film and screen, or parts containing holes or deeply recessed areas are also sources of undercut scatter. Radiographs of such parts will show haziness in the image detail unless effective masking techniques are employed, especially when fluourescent type screens are used in making the exposure.

;CATTER, UNMODIFIED - A scattering process within the material being radiographed, produced from the collision of the original X-ray photons with electrons within the material, with no resultant increase in wavelength.

;CINTILLATION COUNTER - A device for counting atomic particles by means of tiny flashes of light (scintillations) which the particles produce when they strike certain crystals.

;ELF-ABSORPTION - Gamma ray emission from large sources wherein the gamma radiation emitted from the center of the source will be appreciably absorbed by the outer layers of the source material.

;ENSITIVITY - The percent ratio of the thickness of the smallest detectable defect to the thickness of the material being radiographed. Sensitivity is a measure of the capability to detect small discontinuities and, therefore, it involves detail, contrast and density.

;ENSITOMETRIC CURVE - See CHARACTERISTIC CURVE.

;HARPNESS - See UNSHARPNESS.

;HIELDING - Absorptive barriers interposed between a source of radiation and work areas to reduce the intensity of the radiation field to permissible working levels. Concrete or heavy metals such as lead are commonly used for this purpose.

SLOW FILM - Radiographic film that has an emulsion composed of fine or very fine grains characteristic of a slow relative speed film.

SOFT X-RAYS - A term used to express the quality or penetrating power of X-radiation; their penetrating power is relatively light.

SOURCE - The origin of radiation; an X-ray tube or a radioisotope.

SOURCE-FILM DISTANCE - The distance between the focal spot of an X-ray tube or radiation source and the film; generally expressed in inches.

SOURCE SIZE - The diametrical dimension of a radioactive isotope commonly referred to as the isotope focal spot. The actual physical area of the radioisotope constitutes the focal spot size regardless of the geometry of the radioactive source.

SOURCE STRENGTH - A term referring to the current value expressed in milliamperes or microamperes. It also refers to the strength of radioisotopes and radium in curies or millicuries.

SOURCE-WORK DISTANCE - The distance measured from the focal spot of a radiation source to the adjacent or nearest surface of the material being radiographed.

SPECIFIC ACTIVITY - Expressed in curies per gram of material or activity per unit weight (see CURIE). It is particularly pertinent to radioisotopes for radiographic applications. A high specific activity allows the use of a small volume of a given isotope to obtain higher quality radiographs in a given exposure time.

STANDARD, RADIOGRAPHIC - Documents that establish engineering and technical limitations and applications for radiographic processes. Comparison radiographs of flaws or discontinuities picturing limits of acceptability.

STEPPED WEDGE - A device which is used, with appropriate penetrameters on each step, for the inspection of parts having great variations in thickness or a complex geometry. The stepped wedge must be made of material radiographically similar to that being radiographed.

STOP BATH - A chemical solution (or clean running water) used for arresting the activity of the developer remaining in the film emulsion.

SUBJECT CONTRAST - The degree of sharpness with which the X-ray image of an object is projected on the film.

THULIUM 170 - A radioactive isotope suitable for the radiographic inspection of light metals; for example, magnesium and aluminum, and for 1/2 inch steel or its equivalent.

IME-TEMPERATURE COMPENSATION TABLE - A table which indicates the necessary compensation required in case the developer temperature drops below or rises above $68^{\circ}F$. More development time is required if the temperature of the developer solution drops, and less time is necessary if the temperature rises.

WO-FILM TECHNIQUE - A procedure wherein two films of different relative speeds are used simultaneously to radiograph both the thick and the thin sections of an item.

MBRA - See PENUMBRA.

NSHARPNESS, RADIOGRAPHIC - The width of the band of density change on the image of a sharp edge.

VAN DE GRAAF GENERATOR - An electrostatic type X-ray generator in the million and multi-million volt category.

WAVELENGTH - One wavelength is the distance from a given point on a wave to the next corresponding point. By "corresponding point" is meant the point where the wave has the same amplitude and where displacement is in the same direction.

WETTING AGENT - In film processing, a chemical additive to the final water rinse to promote complete wetting of the film, thus assuring adequate washing away and neutralization of the prior processing solutions and prevention of water spots during the drying cycle.

XERORADIOGRAPHY - Radiography, in which a Xerox plate (i.e., generally a photosensitive, selenium coated aluminum sheet) is substituted for the usual X-ray film.

X-RAYS - A form of radiant energy resulting from the bombardment of a suitable target by electrons produced in a vacuum by the application of high voltages. X-rays have wave lengths between 10^{-11} cm and 10^{-6} cm. on the electromagnetic spectrum.

X-RAY TUBE - A glass vacuum tube which contains a hot cathode that emits the electrons, and an anode which decelerates the high velocity electrons and produces X-rays.

ZIRCON SAND - A highly absorptive material used as a blocking or masking medium for drilled holes, slots and highly irregular geometric parts to reduce or eliminate scattered radiation.

-2T RADIOGRAPHY - Quality level of radiography in which the finished radiograph displays a discernable image of a penetrameter hole that has a diameter equal to twice the penetrameter thickness. The penetrameter thickness equals 2 percent of the material thickness.

-2T RADIOGRAPHY - Quality level of radiography in which the finished radiograph displays a discernable image of a penetrameter hole that has a diameter equal to twice the penetrameter thickness. The penetrameter thickness equals 3 percent of the material thickness.

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